

(19) 日本国特許庁 (JP)

## (12) 公開特許公報 (A)

(11) 特許出願公開番号

特開 2000-137906

(P 2000-137906 A)

(43) 公開日 平成12年5月16日 (2000. 5. 16)

(51) Int. Cl. 7

識別記号

F I

テ-マコ-ド (参考)

G 1 1 B 5/39

G 1 1 B 5/39

5D034

審査請求 未請求 請求項の数 28 O L

(全 6 8 頁)

* * *	(21) 出願番号	特願平11-97072 (Application No.)	(71) 出願人	000003078 株式会社東芝
	(22) 出願日	平成11年4月2日 (1999. 4. 2) (Filing Date)	(72) 発明者	福 澤 英 明 神奈川県川崎市幸区堀川町72番地 株式会社東芝川崎事業所内
+ Priority 1.	(31) 優先権主張番号	特願平10-185475	(72) 発明者	上 口 裕 三 神奈川県川崎市幸区堀川町72番地 株式会社東芝川崎事業所内
	(32) 優先日	平成10年6月30日 (1998. 6. 30)	(74) 代理人	100064285 弁理士 佐藤 一雄 (外3名)
+ Priority 2.	(31) 優先権主張国	日本 (J P)		
	(31) 優先権主張番号	特願平10-237821		
	(32) 優先日	平成10年8月24日 (1998. 8. 24)		
	(33) 優先権主張国	日本 (J P)		

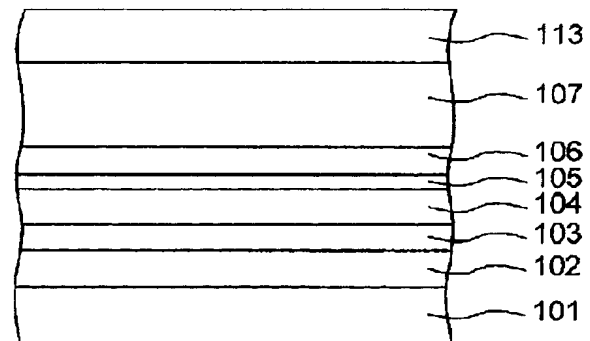
最終頁に続く

(54) 【発明の名称】 磁気抵抗効果素子、磁気ヘッド、磁気ヘッドアセンブリ及び磁気記録装置

## (57) 【要約】

【課題】 バイアスポイントの設計が容易で、高感度且つ高信頼性を有する磁気抵抗効果素子、磁気ヘッド、磁気ヘッドアセンブリ及び磁気記録装置を提供することを目的とする。

【解決手段】 スピンバルブにおいて、フリー層は、印加磁界がゼロの時に前記第2の強磁性体層の磁化方向に対してある角度を成す磁化方向を有し、固着層は、相互に反強磁性的に結合された一対の強磁性体膜とこれらを反強磁性的に結合する結合膜とを含み、さらに、固着層の一対の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段と、前記第1の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第1の強磁性体層に接する非磁性高導電層と、を設けることにより、良好なバイアスポイントを維持しつつ、極めて感度の高い磁気抵抗効果素子を実現することができる。



## 【特許請求の範囲】

【請求項 1】非磁性スペーサ層と、前記非磁性体スペーサ層によって互いに分離された第 1 の強磁性体層と第 2 の強磁性体層と、

を備え、

前記第 1 の強磁性体層は、印加磁界がゼロの時に前記第 2 の強磁性体層の磁化方向に対してある角度を成す磁化方向を有し、

前記第 2 の強磁性体層は、相互に反強磁性的に結合された一对の強磁性体膜と、前記一对の強磁性体膜を分離しつつこれらを反強磁性的に結合する結合膜とを含む磁気抵抗効果素子であって、

前記第 2 の強磁性体層中の前記一对の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段と、

前記第 1 の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第 1 の強磁性体層に接する非磁性高導電層と、

を有することを特徴とする磁気抵抗効果素子。

【請求項 2】前記非磁性高導電層は、バルク状態の室温での比抵抗の値が  $10 \mu\Omega\text{cm}$  以下である元素を含有することを特徴とする請求項 1 記載の磁気抵抗効果素子。

【請求項 3】前記第 1 の強磁性体層の膜厚は  $0.5 \text{ nm}$  以上  $4.5 \text{ nm}$  以下であることを特徴とする請求項 1 または 2 に記載の磁気抵抗効果素子。

【請求項 4】正信号磁界における再生出力の絶対値  $V_1$  と、負信号磁界における再生出力の絶対値  $V_2$  とにより表される波形非対称性  $(V_1 - V_2) / (V_1 + V_2)$  が、マイナス  $0.1$  以上プラス  $0.1$  以下となるように、前記非磁性高導電層の膜厚と前記第 2 の強磁性体層の膜厚とを設定したことを特徴とする請求項 1 ～ 3 のいずれか 1 つに記載の磁気抵抗効果素子。

【請求項 5】非磁性スペーサ層と、前記非磁性体スペーサ層によって互いに分離された第 1 の強磁性体層と第 2 の強磁性体層と、

を備え、

前記第 1 の強磁性体層は、印加磁界がゼロの時に前記第 2 の強磁性体層の磁化方向に対してある角度を成す磁化方向を有する磁気抵抗効果素子であって、

前記第 2 の強磁性体層中の前記一对の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段と、

前記第 1 の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第 1 の強磁性体層に接する非磁性高導電層と、

を有し、さらに、

正信号磁界における再生出力の絶対値  $V_1$  と、負信号磁界における再生出力の絶対値  $V_2$  とにより表される波形非対称性  $(V_1 - V_2) / (V_1 + V_2)$  が、マイナス  $0.1$  以上プラス  $0.1$  以下となるように、前記非磁性高導電層の膜厚と前記第 2 の強磁性体層の膜厚とを設定したことを特徴とする磁気抵抗効果素子。

【請求項 6】比抵抗  $10 \mu\Omega\text{cm}$  の  $\text{Cu}$  に換算した前記非磁性高導電層の膜厚を  $t(\text{HCL})$ 、前記第 2 の強磁性体層中の前記一对の強磁性体膜の膜厚を  $1 \text{ T}$  の飽和磁化で換算した磁気膜厚をそれぞれ  $t_m(\text{pin}1)$ 、 $t_m(\text{pin}2)$  ( $t_m(\text{pin}1) > t_m(\text{pin}2)$  とする) としたときに、 $0.5 \text{ nm} \leq t_m(\text{pin}1) - t_m(\text{pin}2) + t(\text{HCL}) \leq 4 \text{ nm}$ 、且つ  $t(\text{HCL}) \geq 0.5 \text{ nm}$  を満足することを特徴とする請求項 1 ～ 5 のいずれか 1 つに記載の磁気抵抗効果素子。

【請求項 7】非磁性スペーサ層と、前記非磁性体スペーサ層によって互いに分離された第 1 の強磁性体層と第 2 の強磁性体層と、

を備え、

前記第 1 の強磁性体層は、印加磁界がゼロの時に前記第 2 の強磁性体層の磁化方向に対してある角度を成す磁化方向を有する磁気抵抗効果素子であって、

前記第 2 の強磁性体層中の前記一对の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段と、

前記第 1 の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第 1 の強磁性体層に接する非磁性高導電層と、

を有し、さらに、

比抵抗  $10 \mu\Omega\text{cm}$  の  $\text{Cu}$  に換算した前記非磁性高導電層の膜厚を  $t(\text{HCL})$ 、前記第 2 の強磁性体層中の前記一对の強磁性体膜の膜厚を  $1 \text{ T}$  の飽和磁化で換算した磁気膜厚をそれぞれ  $t_m(\text{pin}1)$ 、 $t_m(\text{pin}2)$  ( $t_m(\text{pin}1) > t_m(\text{pin}2)$  とする) としたときに、 $0.5 \text{ nm} \leq t_m(\text{pin}1) - t_m(\text{pin}2) + t(\text{HCL}) \leq 4 \text{ nm}$ 、且つ  $t(\text{HCL}) \geq 0.5 \text{ nm}$  を満足することを特徴とする磁気抵抗効果素子。

【請求項 8】前記非磁性高導電層は、銅 ( $\text{Cu}$ )、金 ( $\text{Au}$ )、銀 ( $\text{Ag}$ )、ルテニウム ( $\text{Ru}$ )、イリジウム ( $\text{Ir}$ )、レニウム ( $\text{Re}$ )、ロジウム ( $\text{Rh}$ )、白金 ( $\text{Pt}$ )、パラジウム ( $\text{Pd}$ )、アルミニウム ( $\text{Al}$ )、オスミウム ( $\text{Os}$ ) 及びニッケル ( $\text{Ni}$ ) よりなる群から選ばれる少なくとも一種の金属元素を含む金属膜であることを特徴とする請求項 1 ～ 7 のいずれか 1 つに記載の磁気抵抗効果素子。

【請求項 9】非磁性スペーサ層と、前記非磁性体スペーサ層によって互いに分離された第 1 の強磁性体層と第 2 の強磁性体層と、

を備え、

前記第 1 の強磁性体層は、印加磁界がゼロの時に前記第 2 の強磁性体層の磁化方向に対してある角度を成す磁化方向を有する磁気抵抗効果素子であって、

前記第 2 の強磁性体層中の前記一对の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段と、

前記第 1 の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第 1 の強磁性体層に接する非磁

性高導電層と、  
を有し、さらに、  
前記非磁性高導電層は、少なくとも2層以上の膜を積層した積層膜から形成されることを特徴とする磁気抵抗効果素子。

【請求項10】前記積層膜のうちで前記第1の強磁性体層に接する膜が銅（Cu）を含むことを特徴とする請求項9記載の磁気抵抗効果素子。

【請求項11】前記積層膜のうちで前記第1の強磁性体層に接しない膜が、ルテニウム（Ru）、レニウム（Re）、ロジウム（Rh）、パラジウム（Pd）、白金（Pt）、イリジウム（Ir）及びオスミウム（Os）よりなる群から選ばれた少なくとも一種の元素を含むことを特徴とする請求項10記載の磁気抵抗効果素子。

【請求項12】前記第1の強磁性体層と反対側の面において前記非磁性高導電層と接して、タンタル（Ta）、チタン（Ti）、ジルコニウム（Zr）、タングステン（W）、ハフニウム（Hf）及びモリブデン（Mo）よりなる群から選ばれた少なくとも一種の元素を含む層を有することを特徴とする請求項1～11のいずれか1つに記載の磁気抵抗効果素子。

【請求項13】前記第1の強磁性体層は、ニッケル鉄（NiFe）を含む合金層とコバルト（Co）を含む層との積層膜からなることを特徴とする請求項1～12のいずれか1つに記載の磁気抵抗効果素子。

【請求項14】前記第1の強磁性体層は、コバルト鉄（CoFe）を含む合金層からなることを特徴とする請求項1～12のいずれか1つに記載の磁気抵抗効果素子。

【請求項15】非磁性スペーサ層と、前記非磁性体スペーサ層によって互いに分離された第1の強磁性体層と第2の強磁性体層と、

を備え、

前記第1の強磁性体層は、印加磁界がゼロの時に前記第2の強磁性体層の磁化方向に対してある角度を成す磁化方向を有する磁気抵抗効果素子であって、

前記第2の強磁性体層中の前記一对の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段としての反強磁性層と、

前記第1の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第1の強磁性体層に接する非磁性高導電層と、

を有し、

前記反強磁性体層の材料として、 $X_zMn_{1-z}$ （ここでXは、イリジウム（Ir）、ルテニウム（Ru）、ロジウム（Rh）、白金（Pt）、パラジウム（Pd）及びレニウム（Re）よりなる群から選ばれる少なくとも一種の元素とし、組成比zは、5原子%以上40原子%以下である）を用いたことを特徴とする磁気抵抗効果素子。

【請求項16】非磁性スペーサ層と、前記非磁性体スペーサ層によって互いに分離された第1の強磁性体層と第2の強磁性体層と、

を備え、

前記第1の強磁性体層は、印加磁界がゼロの時に前記第2の強磁性体層の磁化方向に対してある角度を成す磁化方向を有する磁気抵抗効果素子であって、

前記第2の強磁性体層中の前記一对の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段としての反強磁性層と、

前記第1の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第1の強磁性体層に接する非磁性高導電層と、

を有し、

前記反強磁性層の材料として、 $X_zMn_{1-z}$ （ここでXは、白金（Pt）及びパラジウム（Pd）よりなる群から選ばれた少なくとも一種の元素とし、組成比zは、40原子%以上65原子%以下である）を用いたことを特徴とする磁気抵抗効果素子。

【請求項17】前記非磁性体スペーサ層は、銅（Cu）を含む金属層からなり、且つその膜厚が1.5nm以上2.5nm以下であることを特徴とする請求項1～16のいずれか1つに記載の磁気抵抗効果素子。

【請求項18】前記反強磁性的に結合された前記一对の強磁性体膜は、それらの膜厚が等しいかまたは前記非磁性スペーサ側に接する強磁性体膜の方が厚く、

且つ、前記一对の強磁性体膜は、それぞれの膜厚と飽和磁気との積である磁気膜厚の差が0nmT以上2nmT以下であることを特徴とする請求項1または2に記載の磁気抵抗効果素子。

【請求項19】前記一对の強磁性体膜を反強磁性的に結合する前記結合膜は、ルテニウム（Ru）からなり、且つその膜厚が0.8nm以上1.2nm以下であることを特徴とする請求項1または2に記載の磁気抵抗効果素子。

【請求項20】非磁性中間層を介して配置された少なくとも一对の磁化固着層・磁化自由層と前記磁化固着層に積層された前記磁化固着層の磁化を固着するための反強磁性層とを有する巨大磁気抵抗効果膜、および前記巨大磁気抵抗効果膜に電流を供給するための一对の電極を有する磁気抵抗効果素子において、前記磁化固着層は前記非磁性中間層側に配置された強磁性層Aと前記反強磁性層側に配置された強磁性層Bとからなる一对の強磁性層が磁気結合層を介して反強磁性結合されてなり、前記反強磁性層は最密面ピークのロッキングカーブ半値幅が8°以下となるように最密面が配向されてなることを特徴とする磁気抵抗効果素子。

【請求項21】非磁性中間層を介して配置された少なくとも一对の磁化固着層・磁化自由層と前記磁化固着層に積層された前記磁化固着層の磁化を固着するための反強

磁性層とを有する巨大磁気抵抗効果膜、前記巨大磁気抵抗効果膜に電流を供給するための一対の電極、および前記巨大磁気抵抗効果膜に対する一対の縦バイアス層を有する磁気抵抗効果素子において、前記磁化固着層は前記非磁性中間層側の強磁性層 A と前記反強磁性層側の強磁性層 B からなる一対の強磁性層が磁気結合層を介して反強磁性結合されてなり、前記一対の電極は前記縦バイアス層の間隔よりも狭い電極間隔を有することを特徴とする磁気抵抗効果素子。

【請求項 22】少なくとも 1 層の非磁性中間層と、前記非磁性中間層を介して配置された少なくとも 2 層の磁性層とを有するスピバルブ膜と、前記スピバルブ膜にセンス電流を供給する一対の電極とを具備する磁気抵抗効果素子において、

前記スピバルブ膜は、前記磁性層の前記非磁性中間層とは反対側の面と接する複数の金属膜の積層膜からなる磁気抵抗効果向上層と、前記磁気抵抗効果向上層の前記磁性層とは反対側の面と接する下地機能または保護機能を有する非磁性層とを有し、かつ前記磁気抵抗効果向上層のうち前記磁性層と接する金属膜を主として構成する元素は、前記磁性層を主として構成する元素と非固溶であることを特徴とする磁気抵抗効果素子。

【請求項 23】下側磁気シールド層と、前記下側磁気シールド層上に設けられた下側再生磁気ギャップ層と、前記下側再生磁気ギャップ層の上に設けられた請求項 1～22 のいずれか 1 つに記載の磁気抵抗効果素子と、前記磁気抵抗効果素子上に設けられた上側再生磁気ギャップ層と前記上側磁気ギャップ層の上に設けられた上側磁気シールド層と、を具備することを特徴とする磁気ヘッド。

【請求項 24】感磁部における前記下側再生磁気ギャップ層の表面の凹凸が前記結合膜の膜厚よりも小さいことを特徴とする請求項 23 記載の磁気ヘッド。

【請求項 25】前記第 1 の強磁性体層を膜厚方向にみた中心から前記非磁性スペーサ層を介して前記上側磁気シールド層と前記下側磁気シールド層のいずれか一方に至る距離を  $D_1$ 、前記第 1 の強磁性体層を膜厚方向にみた中心から前記非磁性スペーサ層を介さずに前記上側磁気シールド層と前記下側磁気シールド層のいずれか他方に至る距離を  $D_2$  としたときに、 $D_1 > D_2$  であることを特徴とする請求項 23 または 24 に記載の磁気ヘッド。

【請求項 26】前記上側磁気シールド層と共通化されて設けられた下側磁極と、前記下側磁極上に設けられた記録磁気ギャップ層と、前記記録磁気ギャップ層上に設けられた上側磁極と、を有する記録ヘッドをさらに備えたことを特徴とする請求項 23～25 のいずれか 1 つに記載の磁気ヘッド。

【請求項 27】請求項 26 記載の磁気ヘッドを有するヘッドスライダと、

前記ヘッドスライダが搭載されたサスペンションを有するアームと、

を具備することを特徴とする磁気ヘッドアセンブリ。

【請求項 28】磁気記録媒体と、

前記磁気記録媒体に磁界を印加することにより信号を書き込み、かつ前記磁気記録媒体から発生する磁界を検出することにより信号を読み取る請求項 27 記載の磁気ヘッドを有するヘッドスライダと、

を具備することを特徴とする磁気記録装置。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、磁気抵抗効果素子、磁気ヘッド、磁気ヘッドアセンブリ及び磁気記録装置に関し、より詳細には、本発明は、高感度且つ高信頼性を有するスピバルブ膜を用いた磁気抵抗効果素子、磁気ヘッド、磁気ヘッドアセンブリ及び磁気記録装置に関する。

【0002】

【従来の技術】近年、磁気記録媒体の小型・大容量化が進められていることから、大きな出力が取り出せる磁気抵抗効果 (MR) を利用した磁気ヘッド (MRヘッド) への期待が高まっている。このような MRヘッドの基本構成要素となる MR膜としては、特に磁性層／非磁性層／磁性層のサンドイッチ構造の磁性多層膜を有し、一方の磁性層に交換バイアスを及ぼして磁化を固定しておき (「磁化固着層」、「固着層」あるいは「ピン層」などと称される)、他方の磁性層を外部磁界により磁化反転させ (「感磁層」あるいは「フリー層」などと称される)、これら 2 つの磁性層の磁化方向の相対的な角度変化により巨大磁気抵抗効果 (GMR) を示すスピバルブ膜が注目されている。

【0003】他の MR膜としては、NiFe 合金などからなる異方性磁気抵抗効果膜 (AMR膜) や人工格子膜などが知られている。スピバルブ膜の MR 変化率は、人工格子膜に比べると小さいものの 4% 以上であり、AMR膜と比較すると十分に大きい。さらに、スピバルブ膜は低磁場で磁化を飽和させることができることから MRヘッドに適している。このようなスピバルブ膜を用いた MRヘッドには、実用上大きな期待が寄せられている。すなわち、磁気ディスクなどの磁気記録において、記録密度の高密度化を進めるのには、巨大磁気抵抗効果 (GMR) を用いた高感度な磁気ヘッド、即ち GMRヘッドが必要不可欠となっている。

【0004】初期の GMRヘッドは、磁化自由層 (フリー層)、非磁性中間層、磁化固着層 (ピン層) および反強磁性層からなるスピバルブ膜を GMR素子として用いたものである。しかしながら、記録のトラック幅を狭めて高密度化を行うのに不可欠な感度の向上を図るために、磁化自由層の膜厚を減らすと、磁化固着層からの漏洩磁界が動作点のシフトをもたらすようになり、このシ

フト量を歩留まりよく電流磁界によって補正することが困難となる。

【0005】一方、磁化固着層を磁気結合層を介して反強磁性結合する2層の強磁性層で構成した、いわゆる積層フェリ固着層（以後、「SyAF」、「シンセティックAF」または「反強磁性固着層」と称する）が提案されている（特開平7-169026号公報）。この反強磁性固着層では漏洩磁界を原理的には動作点をゼロにできるので、動作点の確保が容易である。

【0006】即ち、この磁化固着層の2つの強磁性層の非磁性中間層側を強磁性層A、反強磁性層側を強磁性層Bとすると、強磁性層Aと強磁性層Bの磁気膜厚、即ち膜厚×飽和磁化が等しいSyAFでは、強磁性層Aと強磁性層Bの漏洩磁界は互いに打ち消し合うので漏洩磁界は実質的にゼロとなり、また磁化固着層が磁界には感応しなくなるために、固着磁化の安定性が反強磁性層の交換バイアスが消失するブロッキング温度 $T_b$ 近傍まで良好であるなど、大きなメリットを有する。

【0007】

【発明が解決しようとする課題】しかし、従来提案されているこれらの磁気抵抗効果素子においては、種々の問題があった。

【0008】まず、第1に、感度を向上させるためにフリー層を薄膜化すると、センス電流通電時のバイアスポイント設計が困難となるという問題があった。

【0009】第2に、ブロッキング温度（ $T_b$ ）以上の温度においてSyAFの磁化は不安定になるので、静電放電（ESD）電流がGMR素子に流入すると瞬間的に固着層が $T_b$ 以上の温度に加熱され、磁化の固着が乱れてしまうという問題が生ずる。第3に、磁化の固着を行うためには、 $T_b$ 以上まで温度を上げて、しかもSyAFを構成する磁気結合層を介しての反強磁性結合磁界を上回る強い磁界（通常数kOe以上）を加えることが必要である。このため、反強磁性層として $T_b$ の高い反強磁性体を用い、磁化の固着のために $T_b$ 以上まで温度を上げると、SyAFの磁気結合層と隣接する強磁性層との間に拡散を生じて反強磁性結合が低下する、という問題がある。

【0010】第4に、温度上昇させた状態で磁気結合層を介しての反強磁性結合磁界を上回る強い磁界（特開平9-16920号公報では15kOe）を加えるために、巨大な磁化固着熱処理装置が必要となる。

【0011】第5に、ピン層において反強磁性的に結合された2つ強磁性層の磁気膜厚を異ならせた非対称構造のSyAFにすると、外部磁界に感応するために磁化固着は容易になるが、その反面で対称SyAFの優れた耐熱性が失われることになるので、今後の高密度記録において必要とされる磁気ヘッドの耐熱性の要件、即ち200℃前後で磁化固着が安定であること、を満たすのが困難となるという問題が生ずる。また、漏洩磁界の発生を

伴うことになるので、動作点の確保の対策も必要となるという問題も生ずる。

【0012】第6に、SyAFが対称系であっても非対称系であっても、磁気結合層と強磁性層Bが低抵抗であるため、センス電流の分流を生じてGMR素子としての抵抗変化率を低下させてしまうという問題点もある。

【0013】さらに、以上列挙した6つの問題点に加えて、（1）耐熱性が悪い（特に初期プロセスアニールに対して）、（2）再生感度のより一層の向上を図る上でMR変化率が不足している、（3）比較的大きなMR変化率が得られるCoFe合金層単層で感磁層を構成した場合に磁歪制御ができず、良好な軟磁気特性が得られない、などの問題もあった。

【0014】本発明は、上述した種々の課題の認識に基づいてなされたものである。すなわち、その目的は、バイアスポイントの設計が容易で、高感度且つ高信頼性を有する磁気抵抗効果素子、磁気ヘッド、磁気ヘッドアセンブリ及び磁気記録装置を提供することにある。

【0015】

【課題を解決するための手段】上記目的を達成するために、本発明の磁気抵抗効果素子は、非磁性スペーサ層と、前記非磁性体スペーサ層によって互いに分離された第1の強磁性体層と第2の強磁性体層と、を備え、前記第1の強磁性体層は、印加磁界がゼロの時に前記第2の強磁性体層の磁化方向に対してある角度を成す磁化方向を有し、前記第2の強磁性体層は、相互に反強磁性的に結合された一対の強磁性体膜と、前記一対の強磁性体膜を分離しつつこれらを反強磁性的に結合する結合膜とを含む磁気抵抗効果素子であって、前記第2の強磁性体層中の前記一対の強磁性体膜のいずれか一方の磁化を所望の方向に維持する手段と、前記第1の強磁性体層と前記非磁性スペーサ層とが接する膜面と反対側の面にて第1の強磁性体層に接する非磁性高導電層と、を有することを特徴とする。

【0016】上記構成により、良好なバイアスポイントを維持しつつ、極めて感度の高い磁気抵抗効果素子を実現することができる。

【0017】上記構成の望ましい実施の形態として、前記非磁性高導電層は、バルク状態の室温での比抵抗の値が $10\mu\Omega\text{cm}$ 以下である元素を含有することにより、低Hc<sub>u</sub>実現、および極薄フリー層におけるスピフィルター効果による高MR変化率の実現が可能となる。

【0018】また、高密度記録用、および非磁性高導電層によるスピフィルター効果によるMR変化率上昇の効果を実現するのに適した構成として、前記第1の強磁性体層の膜厚は0.5nm以上4.5nm以下であることを特徴とする。

【0019】また、正信号磁界における再生出力の絶対値 $V_1$ と、負信号磁界における再生出力の絶対値 $V_2$ とにより表される波形非対称性 $(V_1 - V_2) / (V_1 +$

V2) が、マイナス0.1以上プラス0.1以下となるように、前記非磁性高導電層の膜厚と前記第2の強磁性体層の膜厚とを設定したことを特徴とする。波形非対称性をマイナス0.1以上プラス0.1以下にするためには、必ずしもSyAFを採用する必要はなく、単層のピン層を用いても良い。その場合、3.6nmT以下で、0.5nmT以上の磁気膜厚の単層ピン層を用いることが望ましい。3.6nmT以上では上記した非対称性を満足することが困難であり、0.5nmT以下ではMR変化率が著しく小さくなるからである。

【0020】また、前記非磁性高導電層の膜厚を $t$  (HCL) (ここでは、比抵抗 $10\mu\Omega\text{cm}$ のCu層で換算した)、前記第2の強磁性体層中の前記一对の強磁性体膜の膜厚を1Tの飽和磁化で換算した磁気膜厚をそれぞれ $t_{m(\text{pin}1)}$ 、 $t_{m(\text{pin}2)}$  ( $t_{m(\text{pin}1)} > t_{m(\text{pin}2)}$  とする) としたときに、 $0.5\text{nm} \leq t_{m(\text{pin}1)} - t_{m(\text{pin}2)} + t(\text{HCL}) \leq 4\text{nm}$ 、且つ $t(\text{HCL}) \geq 0.5\text{nm}$ を満足することを特徴とする。この関係を満足すれば、 $t_{m(\text{pin}2)} = 0$ すなわち単層のピン層を用いても良い。上記関係を満足することにより、波形非対称性がマイナス0.1以上でプラス0.1以下となり、且つ高MRが実現できる。

【0021】また、前記第1の強磁性体層は、その膜厚と飽和磁化との積である磁気膜厚が5nmT未満であることを特徴とする。

【0022】また、前記非磁性高導電層は、低Hin実現という条件を兼ね備えるのに有利となる銅(Cu)、金(Au)、銀(Ag)、ルテニウム(Ru)、イリジウム(Ir)、レニウム(Re)、ロジウム(Rh)、白金(Pt)、パラジウム(Pd)、アルミニウム(Al)、オスミウム(Os)及びニッケル(Ni)よりなる群から選ばれる少なくとも一種の金属元素を含む金属膜であることを特徴とする。

【0023】また、低Hinおよび軟磁性特性制御のために、前記非磁性高導電層は、少なくとも2層以上の膜を積層した積層膜から形成されることを特徴とする。

【0024】この積層膜を用いる場合にも、必ずしもSyAFを採用する必要はなく、単層のピン層を用いても良い。その場合、3.6nmT以下で、0.5nmT以上の磁気膜厚の単層ピン層を用いることが望ましい。3.6nmT以上では上記した非対称性を満足することが困難であり、0.5nmT以下ではMR変化率が著しく小さくなるからである。

【0025】また、前記積層膜のうちで前記第1の強磁性体層に接する膜が、高MR変化率、低Hcu実現、軟磁性実現のために特に優れた材料として銅(Cu)を含むことを特徴とする。

【0026】また、前記積層膜のうちで前記第1の強磁性体層に接しない膜が、低Hin、低Hcu、および軟

磁性制御に特に優れた材料として、ルテニウム(Ru)、レニウム(Re)、ロジウム(Rh)、パラジウム(Pd)、白金(Pt)、イリジウム(Ir)及びオスミウム(Os)よりなる群から選ばれた少なくとも一種の元素を含むことを特徴とする。

【0027】また、低Hcu、高MR変化率の実現のために、前記非磁性高導電層の膜厚は0.5nm以上5nm以下であることを特徴とする。

【0028】また、低Hin、高MR変化率を実現するために、前記第1の強磁性体層と反対側の面において前記非磁性高導電層と接して、タンタル(Ta)、チタン(Ti)、ジルコニウム(Zr)、タングステン(W)、ハフニウム(Hf)及びモリブデン(Mo)よりなる群から選ばれた少なくとも一種の元素を含む層を有することを特徴とする。

【0029】また、高MR変化率と、軟磁性実現のために、前記第1の強磁性体層は、ニッケル鉄(NiFe)を含む合金層とコバルト(Co)を含む層との積層膜からなることを特徴とする。

【0030】また、高MR変化率と、軟磁性実現のために、前記第1の強磁性体層は、コバルト鉄(CoFe)を含む合金層からなることを特徴とする。

【0031】また、前記第2の強磁性体層の磁化固着のために、前記第2の強磁性体層を所望の方向に維持する手段として、反強磁性体層を用いることを特徴とする。第2の強磁性体層は、SyAFであることが望ましいが、単層の強磁性体層でも良い。単層の場合には、その磁気膜厚が0.5nmT以上で3.6nmT以下であることが望ましい。

【0032】また、プロセス熱処理後でも高MR変化率実現のために、前記反強磁性体層の材料として、 $Xz\text{Mn}1-z$  (ここでXは、イリジウム(Ir)、ルテニウム(Ru)、ロジウム(Rh)、白金(Pt)、パラジウム(Pd)及びレニウム(Re)よりなる群から選ばれる少なくとも一種の元素とし、組成比 $z$ は、5原子%以上40原子%以下である)を用いたことを特徴とする。この場合にも、必ずしもSyAFを採用する必要はなく、単層のピン層を用いても良い。その場合、3.6nmT以下で、0.5nmT以上の磁気膜厚の単層ピン層を用いることが望ましい。3.6nmT以上では上記した非対称性を満足することが困難であり、0.5nmT以下ではMR変化率が著しく小さくなるからである。

【0033】また、高MR変化率を維持するために、前記反強磁性層の材料として、 $Xz\text{Mn}1-z$  (ここでXは、白金(Pt)及びパラジウム(Pd)よりなる群から選ばれた少なくとも一種の元素とし、組成比 $z$ は、40原子%以上65原子%以下である)を用いたことを特徴とする。この場合にも、必ずしもSyAFを採用する必要はなく、単層のピン層を用いても良い。その場合、3.6nmT以下で、0.5nmT以上の磁気膜厚の単

層ピン層を用いることが望ましい。3. 6 nmT以上では上記した非対称性を満足することが困難であり、0. 5 nmT以下ではMR変化率が著しく小さくなるからである。

【0034】また、高MR変化率を実現すること、および非磁性高導電層による高MR変化率の効果をより有効に用いること、および低H<sub>c</sub>uを実現するために、前記非磁性体スペーサ層は、銅（Cu）を含む金属層からなり、且つその膜厚が1. 5 nm以上2. 5 nm以下であることを特徴とする。

【0035】また、高MRを実現すること、および耐ESD特性やピン固着層の耐熱性を向上させることを目的として、前記反強磁性的に結合された前記一对の強磁性体膜は、それらの膜厚が等しいかまたは前記非磁性スペーサ側に接する強磁性体膜の方が厚く、且つ、前記一对の強磁性体膜は、それぞれの膜厚と飽和磁気との積である磁気膜厚の差が0 nmT以上2 nmT以下であることを特徴とする。

【0036】また、前記一对の強磁性体膜を反強磁性的に結合する前記結合膜は、ルテニウム（Ru）からなり、且つその膜厚が0. 8 nm以上1. 2 nm以下であることを特徴とする。

【0037】一方、本発明の第1の発明の磁気抵抗効果ヘッドは、非磁性中間層を介して配置された少なくとも一对の磁化固着層・磁化自由層と前記磁化固着層に積層された前記磁化固着層の磁化を固着するための反強磁性層とを有する巨大磁気抵抗効果膜、および前記巨大磁気抵抗効果膜に電流を供給するための一对の電極を有する磁気抵抗効果ヘッドにおいて、前記磁化固着層は前記非磁性中間層側に配置された強磁性層Aと前記反強磁性層側に配置された強磁性層Bとからなる一对の強磁性層が磁気結合層を介して反強磁性結合されてなり、前記反強磁性層は最密面ピークのロッキングカーブ半値幅が8°以下となるように最密面が配向されてなることを特徴とする磁気抵抗効果ヘッドである。

【0038】本発明の第2の発明の磁気抵抗効果ヘッドは、非磁性中間層を介して配置された少なくとも一对の磁化固着層・磁化自由層と前記磁化固着層に積層された前記磁化固着層の磁化を固着するための反強磁性層とを有する巨大磁気抵抗効果膜、および前記巨大磁気抵抗効果膜に電流を供給するための一对の電極を有する磁気抵抗効果ヘッドにおいて、前記磁化固着層は前記非磁性中間層側に配置された強磁性層Aと前記反強磁性層側に配置された強磁性層Bとからなる一对の強磁性層が磁気結合層を介して反強磁性結合されてなり、前記反強磁性層は膜厚が20 nm以下であり、200℃における前記強磁性層Bとの交換結合定数Jが0. 02 e r g / c m<sup>2</sup>以上であることを特徴とする磁気抵抗効果ヘッドである。

【0039】本発明の第3の発明の磁気抵抗効果ヘッド

は、非磁性中間層を介して配置された少なくとも一对の磁化固着層・磁化自由層と前記磁化固着層に積層された前記磁化固着層の磁化を固着するための反強磁性層とを有する巨大磁気抵抗効果膜、および前記巨大磁気抵抗効果膜に電流を供給するための一对の電極を有する磁気抵抗効果ヘッドにおいて、前記磁化固着層は前記非磁性中間層側に配置された強磁性層Aと前記反強磁性層側に配置された強磁性層Bとからなる一对の強磁性層が磁気結合層を介して反強磁性結合されてなり、前記反強磁性層は膜厚が20 nm以下であり、かつZ<sub>x</sub> Mn<sub>1-x</sub>（ZはIr, Rh, Ru, Pt, Pd, Co, Niから選ばれた少なくとも1主であり、0<x<0. 4）、Z<sub>x</sub> Mn<sub>1-x</sub>（ZはPt, Pd, Niから選ばれた少なくとも1種であり、0. 4≤x≤0. 7）、またはZ<sub>x</sub> Cr<sub>1-x</sub>（ZはMn, Al, Pt, Pd, Cu, Au, Ag, Rh, Ir, Ruから選ばれた少なくとも1種、0<x<1）の少なくともいずれか1種を含むことを特徴とする磁気抵抗効果ヘッドである。

10

20

30

40

50

【0040】本発明の第4の発明の磁気抵抗効果ヘッドは、非磁性中間層を介して配置された少なくとも一对の磁化固着層・磁化自由層と前記磁化固着層に積層された前記磁化固着層の磁化を固着するための反強磁性層とを有する巨大磁気抵抗効果膜、前記巨大磁気抵抗効果膜に電流を供給するための一对の電極、および前記巨大磁気抵抗効果膜に対する一对の縦バイアス層を有する磁気抵抗効果ヘッドにおいて、前記磁化固着層は前記非磁性中間層側の強磁性層Aと前記反強磁性層側の強磁性層Bとからなる一对の強磁性層が磁気結合層を介して反強磁性結合されてなり、前記一对の電極は前記縦バイアス層の間隔よりも狭い電極間隔を有することを特徴とする磁気抵抗効果ヘッドである。

【0041】なお、上述した第1乃至第4の磁気抵抗効果ヘッドの構成は、そのまま磁気抵抗効果素子の構成として適用することもできる。

【0042】また本発明の磁気ディスクドライブ装置は、上記の本発明の磁気抵抗効果ヘッドを具備したことを特徴とするものである。そして本出願の磁気ディスクドライブ装置の発明は、上記の本発明の磁気抵抗効果ヘッドの前記磁気抵抗効果素子に電流を供給することにより発生する磁界を用いて、前記磁化固着層の磁化を所定の方向に固着させる機構を有することを特徴とするものである。

【0043】さらに本発明の磁気抵抗効果ヘッドの製造方法は、前記巨大磁気抵抗効果膜の成膜後であって、パターンニングを行う前に、前記強磁性層Aと前記強磁性層Bに対し、磁界中熱処理を行って磁化の方向を所定の方向に固着させることを特徴とするものである。

【0044】一方、本発明の他の形態に基づく磁気抵抗効果素子は、少なくとも1層の非磁性中間層と、前記非磁性中間層を介して配置された少なくとも2層の磁性層

とを有するスピバルブ膜と、前記スピバルブ膜にセンス電流を供給する一対の電極とを具備する磁気抵抗効果素子において、前記スピバルブ膜は、前記磁性層の前記非磁性中間層とは反対側の面と接する複数の金属膜の積層膜からなる磁気抵抗効果向上層と、前記磁気抵抗効果向上層の前記磁性層とは反対側の面と接する下地機能または保護機能を有する非磁性層とを有し、かつ前記磁気抵抗効果向上層のうち前記磁性層と接する金属膜を主として構成する元素は、前記磁性層を主として構成する元素と非固溶であることを特徴としている。

【0045】または、本発明の磁気抵抗効果素子は、少なくとも1層の非磁性中間層と、前記非磁性中間層を介して配置された少なくとも2層の磁性層とを有するスピバルブ膜と、前記スピバルブ膜にセンス電流を供給する一対の電極とを具備する磁気抵抗効果素子において、前記スピバルブ膜は、前記磁性層の前記非磁性中間層とは反対側の面と接する金属の単層膜または積層膜からなる磁気抵抗効果向上層を有し、かつ前記磁気抵抗効果向上層を主として構成する元素は、前記磁気抵抗効果向上層が接する前記磁性層を主として構成する元素と非固溶であると共に、前記磁気抵抗効果向上層は少なくとも貴金属系の合金層を有することを特徴としている。

【0046】または、本発明の磁気抵抗効果素子は、少なくとも1層の非磁性中間層と、前記非磁性中間層を介して配置された少なくとも2層の磁性層とを有するスピバルブ膜と、前記スピバルブ膜にセンス電流を供給する一対の電極とを具備する磁気抵抗効果素子において、少なくとも1層の前記磁性層は、複数の金属の積層膜および合金層の少なくとも一方を有する磁気抵抗効果向上層を介して配置されると共に、磁気的に結合された複数の強磁性膜を有し、かつ前記磁気抵抗効果向上層を主として構成する元素は、前記磁気抵抗効果向上層が接する前記強磁性膜を主として構成する元素と非固溶であることを特徴としている。

【0047】ここで、上記した3種の磁気抵抗効果素子において、磁気抵抗効果向上層は例えば磁性層との界面、積層膜内の界面、下地層や保護層としての非磁性層との界面などで、効果の一例として電子の鏡面反射効果を示すものであり、これによりスピバルブ膜の磁気抵抗効果を向上させるものである。また、フリー層が薄くなった場合には、ここでの磁気抵抗効果向上層は前述した非磁性高導電層として作用し、極薄フリー層と非磁性高導電層の界面を非固溶な材料の組み合わせにより形成することによって、電子のdiffusiveな散乱を解消し、アップスピンの透過率を向上させることによって、高いMR変化率を維持することができる。非固溶な界面なので、熱処理などによっても界面が安定で、MR変化率の低下を解消することができる。本発明における磁気抵抗効果向上層は、鏡面反射効果のみに基づくものではなく、後に詳述するように、さらにスピバルブ膜の結晶

微細構造の制御や磁歪の低減による磁気抵抗効果の向上などももたらすものである。

【0048】また、上記した3種の磁気抵抗効果素子において、磁気抵抗効果向上層の具体的な構成としては、磁気抵抗効果向上層が接する磁性層がCoまたはCo合金からなる場合、Cu、AuおよびAgから選ばれる少なくとも1種の元素を含むことを特徴としている。また、磁気抵抗効果向上層が接する磁性層がNi合金からなる場合、Ru、AgおよびAuから選ばれる少なくとも1種の元素を含むことを特徴としている。磁気抵抗効果向上層にはCu、Au、Ag、Pt、Rh、Ru、Al、Ti、Zn、Hf、Pd、Irなどの元素を含むものを適用することができる。

【0049】磁気抵抗効果向上層に合金層を適用する場合、それを構成する合金としてはAuCu合金、PtCu合金、AgPt合金、AuPd合金、AuAg合金などが例示される。また、磁気抵抗効果向上層に積層膜を適用する場合、積層膜は互いに固溶の関係にある複数の金属膜を有することが好ましい。ただし、非固溶の関係にある複数の金属膜の積層膜を用いることも可能である。

【0050】さらに、上記した3種の磁気抵抗効果素子においては、磁性層と非固溶の関係を有する金属膜の積層膜や合金層を磁気抵抗効果向上層として用い、これを磁性層と接して配置している。また、フリー層が薄くなった場合には、ここでも磁気抵抗効果向上層は前述した非磁性高導電層として作用し、極薄フリー層と非磁性高導電層の界面を非固溶な材料の組み合わせにより形成することによって、電子のdiffusiveな散乱を解消し、アップスピンの透過率を向上させることによって、高いMR変化率を維持することができる。非固溶な界面なので、熱処理などによっても界面が安定で、MR変化率の低下を解消することができる。これら磁気抵抗効果向上層と磁性層との界面は、非固溶の關係に基づいて組成急峻性に優れ、さらにこの状態は熱プロセス後においても保たれる。従って、磁気抵抗効果向上層は鏡面反射膜

(界面反射膜)として有効に機能させることができ、磁気抵抗効果素子の特性向上に大きく寄与する。この磁気抵抗効果特性の向上効果は熱プロセス後においても失われないため、耐熱性に優れた磁気抵抗効果素子を提供することができる。言い換えると、従来のスピバルブ膜ではプロセスアニールにより界面での拡散やミキシングにより損われていたMR特性が、本発明によればプロセスアニール後においても良好に保つことができる。

【0051】上述したような本発明の磁気抵抗効果素子の変形例としては、少なくとも1層の非磁性中間層と、前記非磁性中間層を介して配置された少なくとも2層の磁性層と、前記磁性層のうち少なくとも1層の磁化を固着する反強磁性層とを有するスピバルブ膜と、前記スピバルブ膜にセンス電流を供給する一対の電極とを具

備する磁気抵抗効果素子において、前記反強磁性層は、複数の金属の積層膜および合金層の少なくとも一方を有する磁気抵抗効果向上層と接して配置されており、かつ前記磁気抵抗効果向上層を主として構成する元素は、前記反強磁性層を主として構成する元素と非固溶である磁気抵抗効果素子が挙げられる。

【0052】他の変形例としては、少なくとも1層の非磁性中間層と、前記非磁性中間層を介して配置された少なくとも2層の磁性層と、前記磁性層のうち少なくとも1層の磁化を固着する反強磁性層とを有するスピナル膜と、前記スピナル膜にセンス電流を供給する一対の電極とを具備する磁気抵抗効果素子において、前記反強磁性層は、複数の金属の積層膜および合金層の少なくとも一方を有する磁気抵抗効果向上層と接して配置されており、かつ前記磁気抵抗効果向上層はCu、Au、Ag、Pt、Rh、Ru、Al、Ti、Zr、Hf、PdおよびIrから選ばれる少なくとも1種の元素を含む磁気抵抗効果素子が挙げられる。

【0053】本発明における磁気抵抗効果向上層は、鏡面反射膜、安定な界面によるフリー層が薄い場合の高MR維持としての効果のみならず、膜微細構造の制御に基づく磁気抵抗効果の向上や、CoFe合金などのCo系磁性材料からなる感磁層の磁歪制御に対しても有効に機能する。例えば、Cu下地層単独では例えばCoFe合金の格子間隔が小さくなりすぎ、一方Au下地層単独ではCoFe合金の格子間隔が大きくなりすぎる。これに対して、上述したような積層膜や合金層を用いることによって、感磁層としてのCoやCoFe合金などのCo系磁性材料を低磁歪に有効な格子間隔、すなわちd(111)格子間隔を0.2055~0.2085nmの範囲とすることができる。このような磁歪制御によっても、磁気抵抗効果特性が向上する。

【0054】さらに、スピナル膜の特性向上を図る上で、結晶粒界による原子拡散の抑制なども有効である。結晶粒界での原子拡散を抑えるためには、スピナル膜の結晶粒界を粗大化し、結晶粒界密度を下げるのが好ましい。また、結晶粒界が存在したとしても通常の結晶粒界ではなく、ほとんど面内配向のずれがない、いわゆるサブグレインバウンダリである疑似的な単結晶膜ともいえるべき構造であることが望ましい。このようなサブグレインバウンダリの一例としては、小傾角粒界などが挙げられる。本発明の磁気抵抗効果向上層は、このような小傾角粒界の形成に対しても効果的であり、上述したような金属膜の積層膜や合金層からなる磁気抵抗効果向上層を適用することによって、スピナル膜をfcc(111)配向させ、かつ膜面内における結晶粒間の結晶配向方向のずれを30度以内とすることができる。このようなスピナル膜の結晶粒制御によっても、磁気抵抗効果特性が向上する。

【0055】または、本発明の磁気抵抗効果素子は、上

述したCoFe合金などの磁歪をAu-Cu合金やAu/Cu積層膜で低減する技術に基づくものであり、少なくとも1層の非磁性中間層と、前記非磁性中間層を介して配置された少なくとも2層の磁性層とを有するスピナル膜と、前記スピナル膜にセンス電流を供給する一対の電極とを具備する磁気抵抗効果素子において、前記少なくとも2層の磁性層のうち、外部磁界により磁化方向が変化する磁性層はfcc(111)配向しており、かつd(111)格子間隔が0.2055nm以上であることを特徴としている。

【0056】上述した磁気抵抗効果素子において、磁性層のd(111)格子間隔は0.2055~0.2085nmの範囲であることが好ましい。また、外部磁界により磁化方向が変化する磁性層は、例えばCoまたはCo合金からなる。

【0057】本発明の磁気ヘッドや磁気記録装置は、上述した本発明の磁気抵抗効果素子を用いたものである。すなわち、本発明の磁気ヘッドは、下側磁気シールド層と、前記下側磁気シールド層上に下側再生磁気ギャップを介して形成された、上記した本発明の磁気抵抗効果素子と、前記磁気抵抗効果素子上に上側再生磁気ギャップを介して形成された上側磁気シールド層とを具備することを特徴としている。

【0058】本発明の録再分離型の磁気ヘッドは、下側磁気シールド層と、前記下側磁気シールド層上に下側再生磁気ギャップを介して形成された、上記した本発明の磁気抵抗効果素子と、前記磁気抵抗効果素子上に上側再生磁気ギャップを介して形成された上側磁気シールド層とを有する再生ヘッドと、前記上側磁気シールド層と共通化された下側磁極と、前記下側磁極上に形成された記録磁気ギャップと、前記記録磁気ギャップ上に設けられた上側磁極とを有する記録ヘッドとを具備することを特徴としている。

【0059】本発明の磁気ヘッドアセンブリは、上記した本発明の録再分離型の磁気ヘッドを有するヘッドスライダと、前記ヘッドスライダが搭載されたサスペンションを有するアームとを具備することを特徴としている。また、本発明の磁気記録装置は、磁気記録媒体と、前記磁気記録媒体に磁界により信号を書き込み、かつ前記磁気記録媒体から発生する磁界により信号を読み取る、上記した本発明の録再分離型の磁気ヘッドを備えるヘッドスライダとを具備することを特徴としている。

【0060】

【発明の実施の形態】以下、本発明の実施の形態について図面を参照しつつ詳細に説明する。

(第1の実施の形態：フリー層の薄膜化) 最初に、「フリー層の薄膜化」に関する発明の実施の形態について説明する。

【0061】ここで、本発明の実施の形態について説明する前に、本実施形態に至る過程で本発明者が認識した

「フリー層の薄膜化」に関する課題について詳述する。  
 【0062】磁気抵抗効果素子においては、前述したように、MR変化率のアップに加えて、フリー層の薄膜化（ $M_s * t$  積の減少）によって大幅な感度向上が実現できる。おおまかにいうと、フリー層の  $M_s * t$  積の大きさに反比例して出力は増大する。しかし、本発明者が独自に行った検討の結果、フリー層の薄膜化に関して、以下の問題が生ずることが判明した。

【0063】第1の問題として、センス電流通電時のバイアスポイント設計が困難ということが挙げられる。ヘッド動作時にかかる磁界のすべて足し合わせたときに、トランスファーカーブの線形的な傾きをもっている部分の中央にバイアスポイントがくれば、最適なバイアス状態ということになる。しかしフリー層の膜厚が薄くなると、トランスファーカーブの傾きが急峻になるので、バイアスポイントをトランスファーカーブの線形領域の中央にもってこることが非常に困難になってくる。バイアスポイントが悪くなると、信号のアシメトリ（非対称性）がでてきたり、さらに悪くなると出力レベルが全くとれなくなったりする。

【0064】第2の問題として、従来技術でフリー層を極薄化すると、MR変化率が大幅に低下する問題を生じる。MR変化率の減少は、再生出力の低下をもたらす。

【0065】図7は、以上列挙した2つの問題を説明するための概念図である。すなわち、同図は、磁気抵抗効\*

$$b. p. = 50 \times (H_{shift}/H_s) + 50 \quad (1-1)$$

$$H_{shift} = -H_{in} + H_{pin} \pm H_{cu} \quad (1-2)$$

$$H_s = H_d^{free} + H_k \quad (1-3)$$

$$H_d^{free} = \pi^2 (M_s * t)_{free} / h \quad (1-3-1)$$

$$H_{pin} = \pi^2 (M_s * t)_{pin} / h \quad (1-4)$$

$$H_{cu} = 2 \pi C \times I_s / h \quad (1-5)$$

$$C = (I_1 - I_3) / (I_1 + I_2 + I_3) \quad (1-5-1)$$

ここで、(1-1) 式の  $b. p.$  が、今回注目するバイアスポイント [%] である。最適バイアスポイントは50%であり、マージンまで含めると40~60%が使用可能なバイアスポイントといえる。バイアスポイントがこれらの値からはずれると、アシメトリ（非対称性）がでてきたり、もっとひどい場合には出力が全くとれなくなってしまう。

【0069】バイアスポイント値とアシメトリの関係は、バイアスポイントが40%になったときにはアシメトリが+10%になり、バイアスポイントが60%になったときには、アシメトリが-10%程度になる。後述するように、この計算での最適バイアスポイントは40~60%ではなく、経験上30~50%が最適値となる。

【0070】図8は、計算上のバイアスポイント値とヘッドの再生信号波形の関係を示すグラフ図である。30~50%のバイアスポイント値のときには、アシメトリは比較的小さく、良好な信号波形を示す。ところが、

\*果素子を用いた磁気ヘッドのトランスファーカーブを表し、同図(a)はフリー層が厚い場合、同図(b)はフリー層が薄い場合それぞれ表している。上述したように、フリー層が薄くなると、トランスファーカーブの傾きが急峻になり（ $H_s$  が小さくなる）、またMR変化率が減少することから、 $\Delta V$  が小さくなるという、2つの問題が生じることが図7からわかる。

【0066】上記問題のうち、特にバイアスポイントに関する問題は、膜構造が決定されても容易には認識できず、設計上困難を極めた。今回、本発明者はモデル化した計算を実施し、その結果と経験上得られた「ずれ」とを補正することにより、バイアスポイントを判断することができた。以下にバイアスポイントの計算手法について述べる。

【0067】バイアスポイントは、フリー層に加わる様々な外部磁界によって、シフトする。このシフトは、  
 1. 電流磁界（ $H_{cu}$ ）、2. ピン層からの静磁界（ $H_{pin}$ ）、3. スペーサを介したピン層からの層間結合磁界（ $H_{in}$ ）、4. ハードバイアス膜からの漏洩磁界（ $H_{hard}$ ）の和として近似することができる。上記1~4の磁界の中で、4. のハードバイアス磁界は比較的小さい。そこで、本発明者は、上記1~3の磁界の和に注目して、鋭意検討した。今回用いたバイアスポイントの計算式を以下に示す。

【0068】

その範囲からはずれたところにバイアスポイントがきてしまうと、図8から分かるようにアシメトリが大きくなって、実用上用いることができなくなってしまう。

【0071】 $H_{shift}$  は(1-2) 式で表されるように、フリー層に加わる各磁界の和 [Oe] である。 $H_s$  は図7でも示したように、トランスファーカーブ上での傾きである。

【0072】図9は、これらの各磁界の関係を表す説明図である。

【0073】 $H_d^{free}$  は、あるMRハイト長でのフリー層の反磁界である。 $h$  は、MRハイト長 [ $\mu m$ ] である。 $H_{pin}$  は、ピン層からフリー層に加わるピン漏洩磁界である。 $(M_s * t)_{free}$  は、フリー層のトータルの飽和磁界  $M_s$  と膜厚  $t$  の積であり、 $(M_s * t)_{pin}$  はピン層のネットのピン層（シンセティックAFの場合には上下のピン層の磁気膜厚差分）の飽和磁化と膜厚の積である。

【0074】 $H_{cu}$  は、フリー層に加わる電流磁界であ

り、 $I_s$ は、センス電流 [mA] である。式 (1-5-1) における係数  $C$  は、フリー層の上下の層に流れる電流分流の比である。

【0075】図10は、各層を流れる電流分流  $I_1 \sim I_3$  を表す概念図である。

【0076】ここで説明する計算では、簡単のために、ABS面エッジ部の影響や、シールドの影響は考慮されていない。本発明者の行った計算によるバイアスポイントの見積もりと、実際のヘッドととでは、バイアスポイントが約10%程度、計算のほうがマイナス側にずれることが経験上判明している。最適バイアスポイントのところから、その前後プラスマイナス10%が使用可能な\*

Ta5/NiFe2/Co0.5/Cu2/CoFe2/IrMn7/Ta5 (単位はnm) (1)

上記(1)は、スピバルブの積層構造を表し、各層を構成する元素と層厚 (nm) を表している。この比較例は、いわゆる従来スピバルブ膜でフリー層だけを薄くした従来技術の延長上にある膜である。この膜構成においてバイアスポイントを計算した。

【0078】上述した(1-1)～(1-5)式のバイアスポイント式において、特に求めることが困難なのが、(1-5)式の電流磁界である。その理由は、(1-5-1)式の電流分流比  $C$  を求めることが困難であるからである。薄膜においては、各層の比抵抗は結晶性、および電流分布等の影響を受けて、バルクの比抵抗値とは著しく値が異なるからである。それをできるだけ実際に則した計算を行うため、今回本発明者は以下のような工夫を行うことにより、電流分流比  $C$  を精度よく求めることができた。

【0079】各層の比抵抗を求めるために、上記構成のスピバルブ膜を作製し、ある層の比抵抗を求めたいときには、前後プラスマイナス2nmまで変えた膜を数個作製し、注目する層の膜厚とコンダクタンスの関係を直線で外挿して求めた。そのように求めた理由は、よく用いられる薄膜の単層膜で比抵抗を求める手法では、実際に即した値とはならないからである。結晶性の影響と、電流分布の影響をできるだけ小さくするためには、上下の膜まで実際と同じ材料にして、上述したような微小な膜厚範囲でのコンダクタンス差をみるのが最も精度が良いことが、本発明者の検討によって判明した。

【0080】この手法で求めた各層の比抵抗は、結晶性の影響が小さいだけでなく、電流分布の影響をも含んでいるため、単層膜の比抵抗を用いて単純なパラレルコンダクターで求めた(1-5-1)式の電流分流比  $C$  よりも、かなり精度がよくなる。この手法の採用によって、従来困難だった電流磁界をより精度をあげて計算でも予想できるようになった。

【0081】以上の手法により各層の比抵抗を求めた結果、NiFeは  $20 \mu\Omega\text{cm}$ 、CoFeは  $13 \mu\Omega\text{cm}$ 、スペーサCuは  $8 \mu\Omega\text{cm}$ 、IrMnは  $250 \mu\Omega\text{cm}$  となった。ここで、下地のTa (タンタル) に

\*バイアスポイントということを考慮すると、計算で得られる30%～50%のバイアスポイント値のところが良好なポイントといえる。よって、上に示したような計算で得られたバイアスポイントで30%～50%という値のときには、実用上良好なバイアスポイントが得られたと判断できる。

【0077】以下に具体的に今まで知られているスピバルブ膜を例にとって、上述したバイアスポイント計算式を用いて、問題点を詳しく説明する。

比較例1：通常スピバルブ (スピフィルターなし×シンセティックAFなし)

については膜厚を厚くすると結晶化によって急激に比抵抗が変わり、またキャップTaについても表面酸化物の影響が大きく正確な値を求めることができなかったため、 $100 \mu\Omega\text{cm}$ と仮定した。これらの値を用いて各層の電流分流比を求めて、(1-5)式により電流磁界  $H_{cu}$  を計算した。

【0082】また、 $H_{in}$ の値としては、実測値の250eを用いた。 $H_{pin}$ は(1-4)式により求めた。

【0083】この膜構成では、ピン層厚が厚いままハイト長が短くなるため、ピン層からフリー層に加わる漏洩磁界  $H_{pin}$  が大きくなり、またフリー層の下側よりも上側に多くの電流が流れるのでフリー層に加わる電流磁界  $H_{cu}$  も大きい。よって、バイアスポイントの設計手法として考えられるのは、大きな  $H_{pin}$  を大きな電流磁界  $H_{cu}$  でキャンセルしてバイアスポイント調整しようすることになる。

【0084】センス電流を4mAとしたときに、上記の値を用いて計算したバイアスポイント値の結果を表1に示す。

表1：比較例1の膜の計算で得られたバイアスポイントMR height

0.3 $\mu\text{m}$	70%
0.5 $\mu\text{m}$	61%
0.7 $\mu\text{m}$	53%

表1からわかるように、MRハイト0.3～0.5  $\mu\text{m}$  ではバイアスポイントは61～70%であり、計算上最適なバイアスポイント値と考えられる値よりもオーバーしている。

【0085】図11は、本比較例におけるバイアスポイントの状態を表す概念図である。すなわち、MRハイトを狭めるとバイアスポイントがアンチフェロ側(50%よりも大きい側)にシフトしてしまうことが分かる。MRハイトは機械研磨によって行うため、どうしてもばらつきがでてしまう。このようなMRハイトのばらつきによって、歩留まりが非常に悪くなってしまうことがわかる。これは定性的に言えば、図11に表したように、大きなピン漏洩磁界  $H_{pin}$  を大きな電流磁界  $H_{cu}$  でキャン

セルするという非常に不安定な手法でバイアスポイントを調整しようとしていることに起因する。

【0086】また、バイアスポイント以外にも本比較例の膜は、さらに本質的な問題を有する。それは、本発明で対象としている極薄フリー層を採用すると、MR変化率が低下することである。本発明者が実験的に得た事実として、フリー層の膜厚が薄くなるとプロセス熱処理後のMR変化率が極端に劣化することが大きな問題となる。例えば、比較例1の構成では、as-depo (as-deposited: 堆積したままの状態) でMR変化率は11%程度であるのに対し、プロセス熱処理後ではMR変化率5.6%とas-depoの約半分の大きさにまで減少してしまう。これでは高密度対応のスピバルブ膜を\*

Ta5/Cux/NiFe1.5/Cu2.3/NiFe5/FeMn11/Ta5 (単位はnm) (2)

極薄フリー層におけるMRを改善するために、スペーサ非磁性層と反対側にてフリー層に高導電層を積層した構成のスピバルブ膜が提案されている。例えば、特許第2637360号、米国特許第5422591号、米国特許第5688605号などを挙げることができる。

【0089】上記(2)の膜は、米国特許第5422591号に基づくスピバルブ膜の実施例である。このスピバルブ膜においては、フリー層のスペーサCuとは反対側に接したCu厚を厚くしていくことによって、アップスピンの平均自由行程が長くなることによりMR変化率が上昇してゆき、平均自由行程以上にCu厚を厚くすると単純なシャント層になってしまうため、あるCu厚でMR変化率のピークをとる傾向をもつ。この現象を用いれば、比較例1での1つの問題点だった、極薄フリー層でのMR変化率の減少を一部改善できる。

【0090】しかしながら、米国特許第5422591号に基づく上記(2)のスピバルブ膜では、バイアスポイント、およびMR変化率の耐熱性という、二つの点で問題を抱える膜構成となっている。

【0091】まず、バイアスポイントという観点に関しては、米国特許第5422591号の明細書中には直接的な記載も間接的な示唆も全く開示されていない。そして、(2)の膜は到底実際のヘッドでは採用できない構成である。以下にその理由を詳述する。

【0092】まず電流磁界 $H_{cu}$ を、比較例1と全く同様の方法により実験的に得られた各層の比抵抗を用いて算出した。そのときの各層の比抵抗値としては、Taは $100\mu\Omega\text{cm}$ と仮定し、FeMnは $250\mu\Omega\text{cm}$ 、NiFeは $20\mu\Omega\text{cm}$ 、スペーサCuは $8\mu\Omega\text{cm}$ 、下地Cuは $10\mu\Omega\text{cm}$ と実験的に求めた値を用いた。また、センス電流は4mAとした。 $H_{in}$ については記述がないが、本発明者の追試による結果として150e~250eが得られた。よってここでは、 $H_{in}$ を200eとした。

【0093】素子サイズが、トラック幅 $T_w=0.5\mu\text{m}$ 、MR height=0.3~0.5 $\mu\text{m}$ のときの高密度用

\*実現することはできない。

【0087】さらには、このスピバルブ膜においては各層の膜厚がすべて薄くなってきているので、スピバルブ膜の面抵抗も30 $\Omega$ 程度もの大きな値になり、静電破壊(ESD: Electric Static Discharge)の点からも実用的ではない。よく知られているように、ESDは抵抗が大きければ大きいほど起こりやすくなるからである。

【0088】以上のことから、比較例1の膜は、高密度記録用ヘッドに採用されるような実用的な膜では到底ないことがわかる。

比較例2: 米国特許第5422591号(スピフィルターあり×シンセティックAFなし)

Ta5/Cux/NiFe1.5/Cu2.3/NiFe5/FeMn11/Ta5 (単位はnm) (2)

ヘッドの場合について、バイアスポイントを計算した。その結果を表2に示す。

【0094】表2: 下地Cu厚を変えた場合の比較例2の構成での計算で得られた

バイアスポイント

MR height	Cu 0nm	Cu 1nm	Cu 2nm
0.3 $\mu\text{m}$	126%	143%	156%
0.5 $\mu\text{m}$	111%	127%	140%

この構成では、ピン層からフリー層に加わるピン漏洩磁界 $H_{pin}$ が非常に大きく、バイアスポイントがプラス側にずれやすい構成である。表2のバイアスポイントの計算結果からもわかるように、スピフィルター効果を用いない、下地Cu厚がゼロの場合では、ハイト0.3~0.5 $\mu\text{m}$ で、バイアスポイントが111%~126%とまるで出力がとれないようなところに来てしまっていることがわかる。

【0095】図12は、トランスファーカーブでみたときの $H_{in}$ 、 $H_{pin}$ 、 $H_{cu}$ の大きさとバイアスポイントとの関係を表した概念図である。 $H_{pin}$ が大きいため、電流ゼロの状態でバイアスポイントがかなりオーバーしたところにきてしまい、それを電流磁界によってなんとか50%のほうへもってこようとする設計となる。しかしこの構成では下地に高導電層であるCuを用いているため、図10での $I_3$ が大きくなり、(1-5)式により得られる電流磁界 $H_{cu}$ が小さくなってしまふ。つまり、大きな $H_{pin}$ に対して、逆向きの小さな $H_{cu}$ によってバイアスポイントを50%近傍に引き下げることとなり、バイアスポイントを良好なポイントにもってこることが困難となってしまう。さらに、下地Cu厚をあげるに従って、バイアスポイントがさらに悪くなる様子が表2からわかる。

【0096】以上のような検討を重ねた結果、Gurney特許に記載のあるような構成では、バイアスポイント設計が全くできず、下地に高導電層のCuを設けることによって、バイアスポイントがさらに非現実的な構成になってしまうことが判明した。

【0097】さらに、MR変化率の耐熱性という観点からみても、米国特許第5422591号の膜は実用的な膜とはなっていない。a s - d e p oでのMR変化率の値は米国特許第5422591号に記載のあるように、スピニフィルタ効果によって確かに上昇する。しかし、実際のヘッド作製プロセスを模擬した熱処理後においては、極薄フリー層を用いたときに特有の現象として、MR変化率の値は著しく減少することを本発明者は見いだした。これは、高密度記録用の高出力を得るためには、深刻な問題となる。

【0098】実際に、G u r n e y特許の実施例の膜（上記（2）の膜）により追試すると、下地Cu厚が1\*

Ta5/Cu3/Ta1/NiFe5/Cu2.5/Co2.5/FeMn10/Ta5（単位はnm）（3）

特開平10-261209号明細書に開示されている上記（3）の膜では、Taを介してフリー層に近接するCuシャント層が、比較例2で示した米国特許第5422591号のようにMR変化率のスピニフィルタ効果を目的としたものではなく、電流磁界 $H_{cu}$ を低減させて、センス電流によるバイアスポイントの変動を抑えて、アシメトリーを安定させることを目的としたものである。しかしながら、このような発想は、（3）の膜のように、比較的フリー層が厚い領域においては十分有効だが、本発明でターゲットにしている極薄フリー層のときには、バイアスポイント、およびMR変化率という点で、到底実用的な膜とはならない。以下にその理由について説明する。

【0099】まず、バイアスポイントについては、比較例2の（2）の膜で示したように、極薄フリー層を用いて $H_s$ が非常に小さくなった場合、電流磁界 $H_{cu}$ を低減させても、ピン漏洩磁界 $H_{pin}$ が大きければ最適なバイアスポイントは実現できない。上記（3）の構造が有効なのは、フリー層が厚い、つまり $H_s$ が比較的大きな場合に、一旦最適なバイアスポイントが得られたときに、バイアスポイントのセンス電流依存性が小さいという点である。しかしながら、上記（3）の膜構成でフリー層が極薄になったときには、そもそも最適なバイアスポイントが実現できない。つまり（3）の構成の膜で高密度化対応にするためにフリー層を4.5nm以下にすると、バイアスポイントがプラス側にずれることになる。

【0100】そのことを示すために、計算により求めたこの構成の膜でのバイアスポイントを表3に示す。

【0101】表3：比較例（3）の膜でのバイアスポイント

MR height	NiFe 5nm	NiFe 3nm
0.3 $\mu$ m	86%	108%
0.5 $\mu$ m	83%	104%
0.7 $\mu$ m	81%	100%

ここで $H_{in}$ としては、100eという値を用いた。表3をみると、比較例（3）の構成の膜ではそもそもNiFe膜厚が5nmのときでもバイアスポイントがプラス側

\*nmのときにa s - d e p oでMR変化率が1.8%であったものが、本発明者のプロセスを模擬した熱処理を行うと、0.8%まで劣化する。後に述べるように、この主な原因は反強磁性膜にFeMnを用いていることによる。これでは、高いMR値を実現するのに困難な極薄フリー層を用いたスピニバルブ膜において、せっかくスピニフィルタ効果によって高い値に復帰させたMR変化率を全く機能させていないことになる。つまり、高いMR変化率を示す極薄フリー層スピニバルブ膜を実現するためには、単純なスピニフィルタ効果だけでは達成できないことがわかる。

比較例3：特開平10-261209号

Ta5/Cu3/Ta1/NiFe5/Cu2.5/Co2.5/FeMn10/Ta5（単位はnm）（3）

にずれていて、良い設計とはいえない構成だが、フリー層NiFe膜厚が3nmと薄くなるとますますバイアスポイントがプラス側にオーバーすることがわかる。

【0102】図13は、本比較例におけるバイアスポイントの決定要素の関係を表す概念図である。同図に表したように、 $H_{pin}$ が大きいまま、電流磁界 $H_{cu}$ だけを低減させてしまったためにバイアスポイントがフリー層厚が薄いところでは全くとれない構成になっている。すなわち、電流磁界 $H_{cu}$ と層間結合磁界 $H_{in}$ とピン漏洩磁界 $H_{pin}$ すべての足し算をしたところがゼロになるときが最適バイアスポイント点なので、上記（3）の構造のように電流センターをフリー層に近づけて、電流磁界だけをゼロにしようとしても、全く意味のない膜設計となる。

【0103】さらに、上記（3）の構造が有する第2点目の不具合として、高密度化に必要な高いMR変化率を得られない点を挙げることができる。すなわち、（3）の構造においては、拡散防止層として、比較的高抵抗の材料が高導電層とフリー層の間に挿入されているため、極薄フリー層になったときに、G u r n e y特許で得られているようなMRのスピニフィルタ効果が得られなくなってしまう。後に詳述する本発明で特に威力を発揮するようなフリー層が4.5nm以下の領域では、（3）の構成の膜ではMR変化率が低下してきてしまう。

【0104】以上2点の理由により、上記（3）の構造はあくまでもフリー層が比較的厚い領域での発想であって、極薄フリー層においては到底実用的な膜構成とはならないことがわかった。

【0105】比較例4：スピニフィルタなし×シンセティックAF

Ta5/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5（単位はnm）（4）本比較例においては、ピン特性を向上させるために、シンセティックAF構造を採用した。Ru（ルテニウム）を介した2層の強磁性層は、アンチフェロカップリング（反強磁性結合）している。その一方の強磁性層は反強磁性膜によって一方向に固着

されている。シンセティックAF構造の採用によって、ノーマルピン構造では一方向性異方性磁界 $H_{\text{ua}}$ が小さい場合でも、ある程度の大きさがあれば用いることが可能となり、ピン耐熱性が向上する。また、既に述べたように、シンセティックAF構造では、Ruを介した上下の強磁性層はお互いの磁化方向が逆向きに向いており、その結合磁界は数kOeとヘッド動作時の媒体磁界よりもはるかに大きい。近似的に、外部に与える磁化モーメントは上下のピン層の $M_s \cdot t$ の差がネットのモーメントと考えられる。すなわち、フリー層におよぼすピン漏洩磁界の影響を小さくすることが可能になり、バイアスポイント上有利になることが予想されている（特開平7-169026号）。

【0106】例えば、比較例の場合にはネットのピン厚は0.5nmのピン層と等価と考えられ、ノーマルピン構造では実現不可能な薄いピン層と等価のピン漏洩磁界を実現できる。理想的には、上下のピン層を同じ $M_s \cdot t$ 積に揃えれば、ピン漏洩磁界はゼロということになる。このようなピン漏洩磁界を低減させることのみによって、高密度化対応スピナル膜のバイアスポイント設計は充分だと考えられていた。しかしながら、高密度対応の極薄フリー層においては、シンセティックAF構造だけでは安定したバイアスポイントを実現できないことを、今回本発明者は見出した。以下にその内容を説明する。

【0107】図14は、本比較例におけるバイアスポイントの決定要素の関係を表す概念図である。すなわち、本比較例の構成においては、フリー層はスピナル膜の電流分布の電流センターから大きくはずれたところに位置しているため、電流磁界 $H_{\text{cu}}$ は非常に大きい。 $H_{\text{in}}$ が高々200e程度で、ピン漏洩磁界もシンセティックAF構造の採用によって非常に小さくなっているという

ことは、電流を全く流さない状態で、ほぼジャストバイアスの状態になっている。この構成のスピナル膜で電流を流すと、大きな電流磁界 $H_{\text{cu}}$ により、電流を流せば流すほど、ジャストバイアスからはずれていくことになる。

【0108】本比較例についてのバイアスポイント計算の結果を表4に示す。

【0109】表4：比較例4の膜の計算により得られたバイアスポイント

MR height	$H_{\text{cu}} \uparrow H_{\text{pin}} \uparrow$	$H_{\text{cu}} \downarrow H_{\text{pin}} \uparrow$
0.3 $\mu\text{m}$	88%	22%
0.5 $\mu\text{m}$	80%	16%
0.7 $\mu\text{m}$	73%	10%

ここで $H_{\text{in}}$ として200eという値を用いた。表4から、予想どおり、電流をどちらの向きに流してもバイアスポイントは30～50%の値を実現することができないことがわかる。

【0110】この構造でジャストバイアスを得る手段と

して、ピン漏洩磁界を極力小さくして、つまりシンセティックAF構造で上下のピン層厚を等しく、つまりピン漏洩磁界をほぼゼロにして、かつ $H_{\text{in}}$ をなるべく大きくして、その大きな $H_{\text{in}}$ をキャンセルするように電流磁界でジャストバイアスにもってくる手法が考えられるが、これは望ましくない。大きな $H_{\text{in}}$ というのは単純に外部磁界応答の線形領域をシフトさせるだけではなく、線形領域を減少させる悪影響をもたらし。また、 $H_{\text{in}}$ を小さい値で一定に制御しようとするのはよいが、不自然に大きな値で一定に制御してスピナル膜を作製しようとするのは、大量生産という点から考えても非常に困難で好ましくない。

【0111】また、フリー層のスペーサと反対側の面に高導電層がないので、比較例1と全く同様の理由で極薄フリー層のときにはMR変化率が劣化し、高密度記録用のヘッドとして充分な出力を確保することはできない。これも本質的な問題である。

【0112】以上のように、バイアスポイント、高出力という二つの点から、シンセティックAF構造だけの採用によるスピナル膜では、高密度記録用の極薄フリー層スピナル膜を実現することは到底できない。

【0113】以上詳述したように、本発明者は、比較例1～4のような構成の膜では、高密度記録用の極薄フリー層をもつスピナル膜として、安定したバイアスポイント、充分な高出力は達成することはできないという問題があることを、実際に即した電流磁界の計算と試作を行うことによって明らかにした。そして、さらに独自の試作検討を実施し、以下に詳述する構成を発明するに至った。

【0114】図15は、前述した各比較例のスピナル膜と本発明によるスピナル膜のバイアスポイントのフリー層厚依存性を比較しつつ表したグラフ図である。これまで示してきた各比較例のスピナル膜ではいずれの構成でも、バイアスポイントに大きな問題があることがわかる。ここで、最適なバイアスポイントは、30～50%の範囲にある。そして、感度を十分に得るためには、低い $M_s \cdot t$ において、この範囲内のバイアスポイントを得る必要がある。

【0115】これに対して、各比較例は、いずれも $M_s \cdot t$ が低い条件において、バイアスポイントが最適な範囲から大きく外れている。さらに、 $M_s \cdot t$ に対するバイアスポイントの変動が極めて大きく、バイアスポイントの調節が困難であることがわかる。

【0116】これに対して、後に詳述する本発明の実施例1は、 $M_s \cdot t$ に対するバイアスポイントの変動が極めて小さく、バイアスポイントは、常に最適な範囲内にあることがわかる。

【0117】図15において、比較例1に関して $M_s \cdot t$ が5nmT以上の大きなところでも計算上のバイアスポイントが30%～50%の範囲にはいっていないが、

これは、実際には $M_s \cdot t$ が5 nmT以上のフリー層を用いるような低い記録密度においてはMRハイト長が大きい値であるためである。具体的には、本発明で対象としている記録密度でのMRハイト長 $0.3 \mu\text{m} \sim 0.5 \mu\text{m}$ よりも大きい値であるためである。

【0118】いずれにしても $M_s \cdot t$ が5 nmT以下の領域になってきたところで、本発明の膜と比較例の膜とのバイアスポイント設計の優位差が大きくなることが明確に分かる。

【0119】図16は、上述した比較例1～4の構造において、フリー層の $M_s \cdot t$ だけを小さくした時にMR変化率がどのように変化するかを表したグラフ図である。ここで、縦軸のMR変化率は、図9のトランスファカーブの縦軸にほぼ比例する量である。比較のため、後に説明する本発明の実施例1及び2の膜についても示した。

【0120】ここで、比較例1～4の膜と、本発明の実施例1の膜の $M_s \cdot t$ は、フリー層のNiFe膜厚を変えたサンプルを製作し、実施例2の膜はフリー層のCoFeの膜厚を変えたものを作成した。これらの値は、すべて7 kOeの磁場中で270℃で10時間のプロセスアニールを行った後の結果である。

【0121】また、比較例2と実施例1、2の高導電層は膜厚2 nmのCuとした。フリー層の $M_s \cdot t$ として、比較例のフリー層の膜厚のものを同図中に矢印で示した。また、フリー層の $M_s \cdot t$ としては、NiFeの $M_s$ は1 T、CoFeの $M_s$ は1.8 Tとし、すべて1 TのNiFe換算の膜厚で示した。

【0122】フリー層に接する高導電層を有しない比較例1、3、4の膜では、フリー層の $M_s \cdot t$ が小さくなるとMR変化率が急激に劣化し、高密度化対応の高出力を確保することが困難となる。

【0123】高導電層を有する比較例2の膜ではMR変化率のフリー層 $M_s \cdot t$ 依存性が比較的小さいが、反強磁性膜に貴金属を含まないFeMnを用いているため、プロセス熱処理に対するMR変化率の耐熱性が低い。このような小さなMR変化率では、高密度化の高出力を確保することができない。

【0124】比較例2、比較例3の膜では、スペーサCuとフリー層NiFeとの間に $0.5 \text{ nm}$ のCo若しくはCoFeを挿入すると、1～2%ほど同図中の値よりも大きくなるが、 $M_s \cdot t$ に対する依存性はNiFe単層のフリー層の場合と変わらず、いずれにしてもフリー層の $M_s \cdot t$ が小さいところでのMR変化率は小さな値で十分である。

【0125】一方、本発明によるフリー層に接した高導電層を有するフリー層と、貴金属を有する反強磁性膜を用いると、プロセス熱処理に対するMR変化率の耐熱性も改善し、高密度対応の十分な高出力を得ることができる。特に、5 nmTよりも小さくなったところで、比較

例とのMR変化率の差が大きくなることが分かる。

【0126】以下に、本発明の磁気抵抗効果素子について詳細に説明する。

【0127】図1は、本発明の磁気抵抗効果素子の断面構成を表す概念図である。すなわち、本発明の磁気抵抗効果素子は、高導電層101と、フリー層102と、スペーサ層103と、第1の強磁性体層104と、結合膜105と、第2の強磁性体層106と、反強磁性膜107とを積層した構成を有する。

【0128】この構成により、特に、フリー層102を極薄化したことによるトランスファカーブ上の $H_u$ が小さな場合において、 $H_{cu}$ 、 $H_{pin}$ 、 $H_{in}$ のすべてを小さな値として、 $H_{pin} - H_{in} = H_{cu}$ を実現することにより、良好なバイアスポイントを実現することができる。さらに、一般的に極薄フリー層の場合には高MR変化率が実現しにくくなるのを、良好なMR変化率の耐熱性を維持することによって、高出力のヘッドを実現することができる。

【0129】すなわち、本発明のスピバルブ膜構成によって、高密度用の極薄フリー層を有する場合でも、良好なバイアスポイントが実現でき、かつ高いMR変化率を維持できるため、高出力を安定して得ることができる。具体的には、バイアスポイント設計として、 $H_{pin} - H_{in} = H_{cu}$ を実現することにより良好なバイアスポイントが実現できる。 $H_{pin}$ 、 $H_{in}$ 、 $H_{cu}$ のすべてが小さくすることが、上の式を安定して実現するためには重要である。

【0130】まず、 $H_{pin}$ に対しては、前記第2の強磁性体が反強磁性的に結合したいわゆるシンセティックAF構造を用いることによって、実際に $H_{pin}$ として作用するのは前記第1、第2の強磁性体の2層の磁気的な膜厚の差によるものだけになり、 $H_{pin}$ を低減できる。

【0131】これは、(1-4)式をみても、ピン層の $(M_s \cdot t)_{pin}$ を低減させることが $H_{pin}$ 低減のために有効であるということがわかる。

【0132】しかしながら、極薄フリー層のバイアスポイント設計のためには $H_{pin}$ だけを低減しても全く意味がなく、電流磁界 $H_{cu}$ も低減することが必須である。そのために、非磁性高導電層をフリー層のスペーサとは反対側の面に接しさせることによって、スピバルブ膜中を流れる電流の電流分布の中心をフリー層に近づけることができ、 $H_{cu}$ を低減させることが可能となる。つまり、(1-5)式、(1-5-1)式において、トップタイプのスピバルブ膜のときには $I_3$ が増加し(ボトムタイプのスピバルブ膜のときには $I_1$ が増加する)、電流分流比Cが低下することによって、電流磁界 $H_{cu}$ が抑えられるからである。非磁性高導電層のもう一つの大きな働きとして、本発明で対象としている極薄フリー層のときに、スピフィルター効果によって高いMR変化率を維持できることにある。つまり、非磁性高導

電層を設けることによって、フリー層とスペーサに接する側のピン層の磁化方向が互いに平行状態と反平行状態のときで、アップスピンの平均自由行程の差を大きく保つことができる。

【0133】  $H_{pin} - H_{in} = H_{cu}$  を安定して実現するためには、 $H_{in}$  低減も重要である。上述のような極薄フリー層に接した高導電層による高MR変化率実現（スピンフィルター効果）のためには、スペーサ厚を薄くすることが重要だが、スペーサ厚が薄くなるほど、またフリー層が薄くなるほど  $H_{in}$  は一般的には大きくなりやすい。それを克服して、0～20 Oe 程度の範囲の  $H_{in}$  で本発明を用いることが重要である。

【0134】図2は、本発明のスピンバルブ膜においてえられるトランスファーカーブの概略図である。極薄フリー層を用いた  $H_s$  が小さなトランスファーカーブにおいても、 $H_{pin}$ 、 $H_{cu}$ 、 $H_{in}$  のすべてが低減されている \*

Ta5/Cux/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (単位はnm)

図3は、上記の膜において、フリー層に接しているスペーサとは反対側の高導電層Cuの膜厚に対するフリー層に加わる電流磁界  $H_{cu}$  の関係を表すグラフ図である。ここで、センス電流は4mAとした。同図からわかるように、Cuの膜厚を増加させるほど、(1-5)式のCの値が小さくなることによって、電流磁界  $H_{cu}$  が低減されていく。フリー層よりも上層側と下層側との電流分流比が等しくなったときには、フリー層に加わる電流磁界はいくらセンス電流を流してもゼロ磁界となる。

【0138】ここで、電流磁界を低減させていることが本発明のポイントの一つだが、電流磁界  $H_{cu}$  を完全にゼロにすることは逆に好ましくない。本発明においては、 $H_{pin} - H_{in} = H_{cu}$  を成り立たせることによって、バイ

【0139】電流磁界の観点からすると非磁性高導電層Cu層の膜厚は、大きな範囲でいうと、0.5nm～4nmの範囲内が適正膜厚ということになる。フリー層の膜厚が薄くなるほど  $H_s$  が小さくなっていくため、電流磁界  $H_{cu}$  も小さいほうが望ましくなる。ここでは非磁性高導電層として、Cuを用いたが、ほかの金属材料、もしくは積層膜を用いる場合には、すべてCuに換算した膜厚で考えることができる。例えば、Ru1.5nm/Cu1nmという非磁性高導電層の場合には、実験的に求めた比抵抗はRuは  $30 \mu\Omega\text{cm}$ 、Cuは  $10 \mu\Omega\text{cm}$  なので、Cu換算で  $(1.5\text{nm} \times 10 \mu\Omega\text{cm} / 30 \mu\Omega\text{cm}) + 1\text{nm} = 1.5\text{nm}$  相当のCu膜厚と同等ということになる。

【0140】同様にほかの金属を用いた場合には、実験的に求めた比抵抗として、Cuは  $10 \mu\Omega\text{cm}$ 、Ruは  $30 \mu\Omega\text{cm}$ 、Auは  $10 \mu\Omega\text{cm}$ 、Agは  $10 \mu\Omega\text{cm}$

\*ため、 $H_{pin} - H_{in} = H_{cu}$  の設計が可能となっており、バイアスポイントが50%近傍のよいところに設定することができている。さらに、高導電層によるスピンフィルター効果も用いているため、極薄フリー層においても高MR変化率が維持できており、図2の縦軸も充分大きい値が実現できている。

【0135】次に、バイアスポイントを決定する各要素、すなわち、 $H_{pin}$ 、 $H_{in}$  及び  $H_{cu}$  の各パラメータに関してさらに詳細に説明する。

【0136】まず、低  $H_{cu}$  について説明する。既に説明したように、本発明においてはフリー層のスペーサとは反対側の面に接する側に高導電層を設けることによって、(1-5)式におけるCの値を低減させ、電流磁界  $H_{cu}$  を低減させている。具体的な例として、以下のような膜構成を用いて説明する。

【0137】

m、Irは  $20 \mu\Omega\text{cm}$ 、Reは  $70 \mu\Omega\text{cm}$ 、Rhは  $20 \mu\Omega\text{cm}$ 、Ptは  $40 \mu\Omega\text{cm}$ 、Pdは  $40 \mu\Omega\text{cm}$ 、Alは  $12 \mu\Omega\text{cm}$ 、Osは  $30 \mu\Omega\text{cm}$  という値を用いて電流分流比を求めることができる。また、非磁性高導電層が合金からなる場合には、その主成分の元素の上記の比抵抗の値を用いて、Cu換算の膜厚として計算することができ、元素の組成に応じて比例配分しても良い。

【0141】比較例に関して説明したように、この比抵抗の値は隣接する材料によって変わるが、非磁性高導電層が接する材料は大きく異なることはないので、適正膜厚はこれらの値を用いて求めた値で規定できる。

【0142】また  $H_{cu}$  は(1-5)式でわかるように、フリー層に対して上層と下層との電流分流比によって決まるので、非磁性高導電層とは逆側に位置するスペーサ層の膜厚は  $H_{cu}$  低減という観点から、できるだけ薄いほうが好ましい。これは後の説明のMR変化率のスピンフィルター効果から要求される傾向とも一致する。具体的には、スペーサ膜厚は1.5nm～2.5nm程度が好ましい。

【0143】非磁性高導電層は、電流磁界  $H_{cu}$  低減とともに、MR変化率のスピンフィルター効果をもたらす層としての機能も果たしている。その効果に起因して適性膜厚の範囲もある程度限定される。例えばピン側からのフリー層側に移動する伝導電子を考えると、フリー層の磁化方向がピン層に平行か反平行かで平均自由行程差が大きくなるのが好ましい構成となるので、スピンのアップ、ダウンに依存しないスペーサの厚さは薄いほうが好ましい。 $H_{in}$  が増大しない程度の膜厚ということになると、スペーサ厚は1.5nm～2.5nm程度が好ましい。

【0144】また、フリー層厚はダウンスピンの平均自由行程よりは厚く、アップスピンの平均自由行程よりは

充分薄いほうが好ましい。例えば、NiFeのダウンスピンの平均自由行程は1.1nm程度なので、NiFeの膜厚としては1nm~4.5nm程度が最も好ましく、CoFeの場合には1nm~3nm程度が最も好ましい。高導電層厚はピン厚、スペーサ厚、フリー層厚によって最適膜厚は異なるが、スペーサ厚が薄いほど、またフリー層厚が薄いほどMRのピークをとる高導電層厚の厚さは厚膜側にピークしていく。例えば、ピン層がCoFe2.5nm、Cuスペーサ厚2nm、フリー層厚CoFe2nmの場合には、高導電層にCuを用いた場合10には2nm程度のところでピークをとる。経験上フリー層の膜厚と非磁性高導電層Cuのトータル膜厚が4~5nm程度になるときにMR変化率のピークをとるので、その近傍になるように非磁性高導電層の膜厚を設定するのが好ましい。Cuをフリー層に接する非磁性高導電層に用いている場合にはCu膜厚とフリー層膜厚のトータル膜厚は、マージンも含めて3nm~5.5nm程度が好ましい範囲となる。

【0145】次に、 $H_{pin}$ について説明する。 $H_{pin}$ を低減させるためには、 $B_s$ が1.8TのCoFeで実効的なピン厚を約2nm以下(NiFe換算で3.6nm以下)、さらに望ましくは実効的なピン厚1nm以下(NiFe換算で1.8nm以下)にすることが望ましい。そのピン層の実現手段としては、シンセティックAF構造が望ましい。これは例えば反強磁性膜/強磁性膜1/Ru0.9nm/強磁性膜2という構成からなり、強磁性膜1と強磁性膜2は反強磁性的に磁気結合している。反強磁性的に結合した一方の強磁性膜1は反強磁性膜によって一方向に磁化固着されている。強磁性膜1と強磁性膜2の磁化方向は逆向きでその結合磁界は数kOeと大きい30ため、一次近似として、強磁性膜1の $M_s \cdot t$ と強磁性膜2の $M_s \cdot t$ の差が実効的なピン漏洩磁界に寄与すると考えられる(特開平7-169026号公報)。

【0146】例えば、IrMn/CoFe2/Ru0.9/CoFe2.5(膜厚の単位はnm)という構成では実効的なピン厚は2.5nm-2nm=0.5nm(磁気膜厚は0.9nmT)ということになる。実効的なピン層厚が低減できると、(1-4)式からわかるように、 $H_{pin}$ を低減できる。このように、シンセティックAF構造は、本発明のバイアスポイントという点で、極薄フリー層を使いこなすには必須の構造である。

【0147】次に、 $H_{in}$ について説明する。バイアスポイントおよびスピントラ効果の点からいうと、スペーサとして使われるCu層の厚さはできるだけ薄くすることが望ましいことを既に述べた。そのような薄い膜厚での具体的な $H_{in}$ の値としては、0~200e、さらに望ましくは、5~150e程度に抑えることが望ましい。本発明の一つの解決方法として、スペーサが薄いときでも $H_{in}$ を増大させないような膜構成として、二層下

地構成などがあげられる。

【0148】次に、MR変化率の耐熱性について説明する。極薄フリー層を用いた場合には、MR変化率のプロセス熱処理に対する耐熱性を維持することも、著しく困難になる。具体的には、極薄フリー層スピントラ膜のMR変化率耐熱性を改善するために大きくわけて2つの施策がある。その1つがある一定以上の非磁性高導電層をフリー層に接して設けることである。非磁性高導電層はスピントラ効果としての役割ももちろんあるが、MR変化率の耐熱性を向上させるという役割も果たすことが明らかになった。これはフリー層の膜厚が4.5nm程度ではそれほど顕著ではないが、2nm程度にまで薄くなると、非磁性高導電層のトータル膜厚として、1nm以上は必須であることがわかった。例えば、非磁性高導電層が0nmのときには、as-depoのMR変化率とプロセス熱処理後(270℃×10時間)のMR変化率では相対比で約50%も減少してしまうが、1nm程度の非磁性高導電層を設けることによって、0~30%の減少に抑えることができる。

【0149】さらにこれだけではまだMR変化率の熱劣化率にばらつきがある。この原因が2つ目の施策である、反強磁性膜材料の差である。反強磁性膜として、FeMnなどを用いているときに、上記の熱劣化率30%の場合である。ところが、反強磁性膜材料としてIrMnを用いているときには、0~15%の劣化率まで低減させることができる。さらに、PtMnを用いているときにはas-depoのMR変化率は測定不能だが、おおむねIrMnのas-depoのMR変化率の値、つまり熱劣化率0%を実現することができる。これは、反強磁性膜材料の貴金属濃度を含むかどうか依存しており、IrMn、PtMn、PdPtMn、RuRhMnのような貴金属を含む反強磁性膜を用いることが、本発明による極薄フリー層のスピントラ膜には特に望ましいことが判明した。

【0150】図4は、以上のまとめとして、アシメトリが-10%~+10%、つまり、バイアスポイント30%~50%を実現するためのシンセティックAFのピン層厚と、非磁性高導電層厚との具体的な範囲を表したグラフ図である。ここで、「アシメトリ」すなわち「波形非対称性」とは、正信号磁界における再生出力の絶対値V1と、負信号磁界における再生出力の絶対値V2とにより、 $(V1 - V2) / (V1 + V2)$ と定義する。従って、「アシメトリが-10%~+10%」とは、

$(V1 - V2) / (V1 + V2)$ の値が、マイナス0.1以上プラス0.1以下であることに対応する。

【0151】 $H_{pin} - H_{in} = H_{cu}$ を実現するために、 $H_{pin}$ が小さくなったときには、 $H_{cu}$ も下げなければならない。つまり、式(1-4)、(1-5)からわかるように、シンセティックAFの上下のピン層厚( $M_s \cdot t$ )<sub>pin</sub>を小さくした時には、非磁性高導電層の膜厚

を厚くしなければならず、 $(Ms \cdot t)_{pin}$ を大きめの値にしたときには、非磁性高導電層の膜厚を薄くしなければならない。

【0152】具体的には、シンセティックAFを形成する厚いピン層の膜厚を $t_m(pin1)$ 、薄いピン層の膜厚を $t_m(pin2)$ 、非磁性高導電層の膜厚を $t(HCL)$ （比抵抗 $10 \mu\Omega cm$ のCu層に換算した）としたときに、 $0.5 nm \leq t_m(pin1) - t_m(pin2) + t(HCL) \leq 4 nm$ 、かつ $t(HCL) \geq 0.5 nm$ を満足するところが本発明の範囲である。ここで、 $0.5 nm \leq t_m(pin1) - t_m(pin2) + t(HCL)$ はバイアスポイントが30%近傍、つまりアシメトリが+10%になる限界であり、 $t_m(pin1) - t_m(pin2) + t(HCL) \leq 4 nm$ はバイアスポイントが50%近傍、つまりアシメトリが-10%になる限界である。

【0153】ここで、 $t_m(pin1) - t_m(pin2)$ は、 $Ms$ が1TのNiFeに換算したときの磁気膜厚であり、例えば、PtMn/CoFe2/Ru0.9/CoFe2.5という構成のシンセティックAF構造のときには、 $(2.5 - 2) \times 1.8 T = 0.9 nm$ ということになる。また、比較のために示した比較例の単層pin構造の場合には、単層pin層の $(Ms \cdot t)$ を用いる。

【0154】また、 $t(HCL)$ は非磁性高導電層をCu換算の膜厚にした場合であり、Cu以外の非磁性高導電層を用いる場合には、前述した比抵抗値を用いてCu換算の膜厚にすることができる。

【0155】また、 $t(HCL) \geq 0.5 nm$ は、4.5 nmよりも薄いフリー層における、高MR実現のために必要な非磁性高導電層の膜厚の下限値を規定するものである。また、上記範囲のさらに好ましい範囲として、非磁性高導電層の膜厚が3 nm以上になると、 $\Delta R_s$ が低下する場合があるので、 $t(HCL) \leq 3 nm$ が望ましい。また、シンセティックAFの上下ピン層厚の差が3 nm以上になると、ピン層の磁化固着の耐熱性が劣化するので、 $t_m(pin1) - t_m(pin2) \leq 3 nm$ であることが望ましい。

【0156】図4においては、前述した比較例1~4と、後に詳述する本発明の実施例1の膜のデータをプロットした。ここで、シンセティックAF構造の場合には、スペーサ層側のピン層が、もう一方のピン層よりも磁氣的膜厚が厚い場合には、横軸のピン層の磁気膜厚をプラス側とし、スペーサ層側のピン層がもう一方のピン層よりも磁気膜厚が薄い場合には、横軸のピン層の磁気膜厚をマイナス側にとることとした。シンセティックAFを用いない従来のピン層の場合には、ピン層の磁氣的膜厚はすべてプラス側にとることとした。

【0157】同図からわかるように、比較例は全て良好な範囲から外れ、バイアスポイントが悪い、つまりアシ

メトリが大きい、本発明によれば、良好なバイアスポイント、つまりアシメトリが小さい膜が実現できる。

【0158】以上説明した本発明による、シンセティックAFによる小さな $H_{pin}$ を、小さな $H_{cu}$ によってキャンセルする、つまり $H_{pin} - H_{in} = H_{cu}$ を実現するバイアスポイント設計と、極薄フリー層スピンバルブ膜に特有のMR変化率の耐熱性の困難点を克服した、具体的な膜構成について示す。

（実施例1）トップSFVS（NiFe/Co(FE)フリー層）Ta5/Cux/NiFe2/CoFe0.5/Cu2/CoFe(2+y)/Ru0.9/CoFe2/IrMn7/Ta5 (7-1) まず、反強磁性膜がフリー層よりも上層側に位置する、いわゆるトップタイプのスピンバルブ膜の実施例について説明する。

【0159】図5は、本実施例の磁気抵抗効果素子の具体的な膜構成を示す概念図である。すなわち、下地パツファ層12の上に、本発明による特有の高導電層101、その上にフリー層102、スペーサ層103、が積層され、強磁性ピン層104、106が、105を介して反強磁性的に結合し、106のピン層が反強磁性層107によって一方向に固着されている。反強磁性層107の上には、キャップ層113が設けられている。(7-1)の膜構造は、フリー層102が110、111の二層の積層膜からなり、非磁性高導電層101が単層Cuからなるタイプのものである。

【0160】(7-1)の膜は、Cu下地によるMRのスピンフィルター効果、電流磁界 $H_{cu}$ 低減効果と、シンセティックAFによる $H_{pin}$ 低減効果を用いて、MRとバイアスポイントとを両立した膜となる。この膜に関して、前述した方法によりバイアスポイントを計算した結果を表5に示す。

【0161】表5 バイアスポイント計算結果

(a)  $y = 0.5$   $H_{in} = 20$  Oe

MR height	x = 2
0.3 $\mu m$	37%
0.5 $\mu m$	31%
0.7 $\mu m$	25%

(b)  $y = 0.8$   $H_{in} = 20$  Oe

MR height	x = 2
0.3 $\mu m$	46%
0.5 $\mu m$	40%
0.7 $\mu m$	33%

(c)  $y = 0.5$   $H_{in} = 10$  Oe

MR height	x = 2
0.3 $\mu m$	42%
0.5 $\mu m$	39%
0.7 $\mu m$	36%

ここで下地Cu厚は、2 nmとした。単純な単層の高導電層からなる単層のCu下地のときには $H_{in}$ が20 Oeと若干大きめの値となる。そのときにはシンセティックAFのピン厚差が0.5 nmでは良好なバイアスポイン

ト値の40%よりも若干マイナス側にずれることが、表5(a)の結果からわかる。これでも充分実用的な膜であるが、 $y=0.8\text{ nm}$ と $H_{pin}$ を若干増大させた場合が、表5(b)の結果である。これによって、表5

(a)のようにバイアスポイントがアンダー気味にずれていた場合には、バイアスポイントを良好な値に近づけることが可能になる。また、表5(c)のように、 $H_{in}$ を下げて同様にバイアスポイントを良好な値にすることができる。表5(a)、(b)と(c)を比べてみれば明らかのように、 $H_{in}$ が小さいほうが、バイアスポイントのハイト依存性が小さくなるため、 $H_{in}$ はできるだけ低減することが望ましい。シンセティックAF構造の上下ピン厚差は小さいほうが、 $H_{pin}$ が小さくなりハイト依存性が小さくなるが、(a)と(b)の0.3nmぐらいの差ではほとんど影響がないので、 $y=0\sim 1\text{ nm}$  ( $Ms \cdot t=0\sim 1.8\text{ nmT in NiFe}$ )が好ましく、さらに望ましくは $y=0\sim 0.5\text{ nm}$  ( $0\sim 0.9\text{ nmT in NiFe}$ )の範囲が、バイアスポイントとともに、耐ESD対策等の特性向上なども考慮にいれてyの値の調整が可能であるため望ましい。

【0162】下地Cu厚はバイアスポイント調整とともに、MRのスピニフィルター効果も用いている。下地Cu厚を厚くすれば $H_{cu}$ が小さくなるが、 $\Delta Rs$ が低減してしまうため、Cu厚0.5nm~5nm、特に望ましくは0.5~3nmが好ましい。MRのスピニフィルター効果が得られる下地Cu厚はフリー層構成に依存し、フリー層厚が薄いときほど、MRのスピニフィルター効果が得られる下地Cu厚の最適厚さは厚いほうにシフトする。実験的に得られた結果では、下地Cu厚と磁性フリー層の膜厚の和が4nm~5nmのときにMR変化率がピーク値をとる。

【0163】(7-1)のようなフリー層構成の場合には、下地Cu厚が0~1.5nmまではCu厚増加によるスピニフィルター効果によるMR増加と、Cu厚増加によるRs低減の効果がちょうどキャンセルし、 $\Delta Rs$ はほとんど変化がない。1.5nm~2nmでは、 $\Delta Rs$ が約0.1 $\Omega$ 、1.5nm~3nmでは、 $\Delta Rs$ が0.25 $\Omega$ 減少してしまう。 $\Delta Rs$ の低下はそのまま出力低下にほぼ比例してしまうため、好ましくない。しかし、バイアスポイント上、下地Cu厚が厚くすることが望ましい場合には、このフリー層構成で、下地Cu厚3nmを用いることも考えられる。このときには、単位電流あたりの電流磁界は小さく、かつスピニバルブ膜抵抗も低下しているため、 $\Delta Rs$ の低下による出力低下を、電流を多めに流すことによって回復する手法が考えられる。出力も電流量にほぼ比例するからである。下地Cu厚を増加することによって $\Delta Rs$ が10%低下したときには、例えばセンス電流をこれまでの計算の4mAから5mAにすることによって25%増加するので、 $\Delta Rs$ 低下の分を十分に補うことができる。

【0164】フリー層厚が厚いNiFe4/CuFe0.5(nm)の場合には、下地Cu厚は0.5~2nm程度が好ましく、フリー層が薄いNiFe1/CuFe0.5nmの場合には、下地Cu厚は、1~4nm程度が好ましい。また界面CuFeの厚さは0.3~1.5nmの範囲で変えても構わない。また、CuFeのかわりに、Co、もしくは他のCo合金を用いても構わない。CuFeのかわりにCoを用いる場合にはCo単体では軟磁性が実現できないため、できるだけ薄くすることが望ましい。

【0165】例えば、NiFeが4nmのときにはCoは0~1nm、NiFeが2nmのときには、0~0.5nm、NiFeが1nmのときには、0~0.3nmが好ましい。また、下地Cuとの界面拡散を気にする場合には下地Cuとの界面にもCuと非固溶な材料のCoやCuFeを挟んでも構わない。例えば、Co0.3/NiFe2/Cu0.5、CuFe0.5/NiFe2/CuFe0.5などのフリー層が考えられる。

【0166】また、このような極薄磁性膜の積層膜にするかわりに、NiFeCoの合金フリー層を用いてもよい。

【0167】また、本発明で対象にしているような極薄フリー層では低磁歪を実現することも困難になる。一つの困難点として、NiFeの膜厚が薄くなるほど、NiFeの磁歪が正に大きくなることが挙げられる。それを克服するために、通常NiFe8nm/CuFe1nmというフリー層ではNiFeの組成はNi<sub>80</sub>Fe<sub>20</sub>(at%)で良いが、本発明の4.5nmT以下のフリー層の場合には、Ni<sub>80</sub>Fe<sub>20</sub>よりもNiリッチにすることが望ましい。具体的には、NiFe膜厚が4nm程度のときでNi<sub>81</sub>Fe<sub>19</sub>(at%)よりもNiリッチに、NiFe膜厚が3nm程度のときにはNi<sub>81.5</sub>Fe<sub>18.5</sub>(at%)よりもNiリッチにすることが望ましい。Ni濃度の上限としては、Ni<sub>90</sub>Fe<sub>10</sub>(at%)程度が好ましい。

【0168】上記のように、下地Cuは電流磁界 $H_{cu}$ を低減させて、極薄フリー層においても良好なバイアスポイントを実現するという目的と、極薄フリー層でもMR変化率の劣化なくスピニフィルター効果を用いるということが2つの大きな目的である。

【0169】バイアスポイントという点からいうと、上記(7-1)の膜でyとxは独立に決められるものではなく、相互の値に注意して決定される。例えば、yが小さくなると $H_{pin}$ が小さくなるため、それをキャンセルする電流磁界 $H_{cu}$ も小さいほうがよいので、xの値は大きめの値のほうに最適点がシフトする。

【0170】具体的には、一つの例として次のような膜厚設計が考えられる。非磁性高導電層がCu層の場合の設計として、ピン層が2nmTのときにはCu層は0.5~1.5nm、ピン層が1.5nmTのときにはCu

層は1~2 nm、ピン層が1 nmTのときにはCu層は1.5~2.5 nm、ピン層が0.5 nmTのときにはCu層は2~3 nm、ピン層が0 nmTのときにはCu層は2.5~3.5 nmということになる。

【0171】ここでピン層がCo、もしくはCoFeのときにはピン層の膜厚は $t = (Ms * t)_{pin} / 1.8 T$  [nm]、ピン層がNiFeのときにはピン層膜厚は $t = (Ms * t)_{pin} / 1 T$  [nm]ということになる。

【0172】スペースCuはCuの他に、Au、Ag、またはこれらの元素を含む合金などを用いても構わない。しかし最も望ましいのは、Cuである。高いMRを実現すること、およびフリー層の下地側とは反対側のシャント層をできるだけ小さくして電流磁界を低減させるためにも、スペース厚さは、できるだけ薄いほうが好ましい。しかし、あまり薄すぎるとピン層とフリー層のフェリ的な磁気結合が強くなってしまい、 $H_{in}$ 増大が生じてしまうので、1.5 nm~2.5 nm、さらに望ましくは、1.8~2.3 nm程度が望ましい。

【0173】スピンフィルター効果と電流磁界低減のために大きな役割を果たしている下地高導電層は、ここでは単層のCuで構成されているが、積層膜で形成しても構わない。このとき、トップスピンバルブ膜においては、fccのシード層という役割もあるため、下地材料としては、fccもしくはhcp金属材料がよい。具体的には、Au、Ag、Al、Zr、Ru、Rh、Re、Ir、Ptなどからなる金属の合金層、もしくは積層膜が考えられる。MRのスピンフィルター効果と電流磁界低減効果だけのためなら単純なCu下地で十分効果が得られるが、下地材料をわざわざ合金層や積層膜にする効果として、極薄フリー層の磁歪制御と $H_{in}$ 制御という2つの役割がある。具体的には次のような実施例が考えられる。

【0174】Ta5/Ru1/Cu1.5/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (7-2) Ru 1 nmを下地として用いることによって、膜の平坦性が向上し、スペース2 nmでフリー層の $Ms * t$ がNiFe換算2.9 nmTと極薄フリー層にも関わらず100 e程度の低 $H_{in}$ を容易に実現することができる。低 $H_{in}$ の実現はバイアスポイントのMRハイト依存性がすくなくなるという点で望ましい。また、いたずらにシンセティックAFの上下ピン層の膜厚差をつけなくても良好なバイアスポイントが実現できるという点でも好ましい。ここではRuの膜厚は1 nmとしたが、0.5 nm~5 nm、さらに望ましくは、1 nm~3 nm程度が望ましい。Ru以\*

Ta5/Cux/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (7-3)

Ta5/Rux/Cuy/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (7-4)

PtMn (Pt: 40~65 at%) を使うメリットとしては、貴金属濃度がIrMnよりもさらに高いためプロセスアニールによるMR劣化がさらに少なく、高いM

\* 外の材料でも望ましい膜厚はそれほど変わらない。

【0175】(7-2)の膜では、 $H_{cu}$ を計算するときには、Ruの厚さとCuの厚さの電気的なシャント層の足し算になる。例えば、Ruの場合には、 $30 \mu\Omega cm$ とCuの比抵抗の約3倍なため、 $H_{cu}$ という観点では(7-2)の膜はCu厚換算で1.8 nmの膜と同等ということになる。ただしMRという観点ではRuでは抵抗が高く、電子の平均自由行程が短いため、RuをNiFeにダイレクトに接しさせることではスピンフィルター効果はほとんど得られない。よって、フリー層に接する層としては、できるだけ低抵抗のCu、Au、Agなどが望ましく、Ruなどの材料はCu、Au、Agなどを介して二層にすることが好ましいわけである。これがわざわざ二層下地にする1つの理由である。

【0176】また、ここではバッファ層TaとRuをわけて考えたが、Ru層がバッファ層としての効果も発揮するならばTa層はなくてもよい。例えばZr層をRuの代わりに用いるときなどは、Taをなくすことも可能である。

【0177】バッファ層を用いる場合には、Taの他に、Ti、Zr、W、Cu、Hf、Moもしくはこれらの合金などを用いることができる。これらのいずれの材料を用いても、膜厚は1 nm~7 nm、さらに好ましくは、2 nm~5 nm程度が好ましい。

【0178】ここではAF膜としてIrMn (Ir: 5~40 at%)を用いたが、IrMnの膜厚としては、3 nm~13 nm程度が好ましい。IrMnを用いるメリットとしては、薄い膜厚でも良好なピン特性が実現できるため、高密度化に向けた狭ギャップヘッドに適している、貴金属を含んでいるため、熱処理後に高MR変化率を維持できるという特徴がある。比較例2で示したようなFeMnを反強磁性膜に用いた膜では、高MR変化率を熱処理後に維持することはできない。これは本発明のような極薄フリー層を用いるときに顕著に表れる現象である。

【0179】また、反強磁性膜としてはCrMn、NiMn、NiOを用いても良いが、高MR変化率実現のためには、貴金属元素を含むAFが望ましい。たとえばIrの代わりにPd、Rhなどを用いても良い。FeMnやNiMnなどに比べてMR変化率が向上するため、ヘッドに不可欠なアニール熱処理後も高MR変化率が維持される。また、貴金属元素の濃度がさらに高いPtMnを用いることも望ましい実施例のひとつである。

【0180】

R変化率が実現でき、 $\Delta Rs$ を大きくすることができ、高出力が得られることが挙げられる。MRの良好な耐熱性を実現しにくい極薄フリー層のスピンバルブ膜におい

て、スピニフィルター効果による下地Cuなどがある構成と、PtMnとの組み合わせが最もMR耐熱性がよい。PtMnの代わりにPdMn、PdPtMnを用いても良い（貴金属濃度：40～65at%）。

【0181】MR耐熱性という観点からいうと、下地Cu厚は1nm以上あることが望ましい。それ以下の膜厚だとMRの耐熱性が悪くなるからである。ただし、NiFeの膜厚が4nm以上あるときには、下地Cu厚は0.5nm以上あればMRの耐熱性を確保できる。

【0182】PtMnは電気的な抵抗の値もIrMn 10 とほぼ同じ値で大きいので、電流磁界に対する寄与は小さく好ましい。このように、(7-3)、(7-4)の膜は実用上非常に優れた膜である。

【0183】ただし、PtMnのデメリットとして一方異方性磁界がでる臨界膜厚がIrMnの場合よりも厚いため、5nm程度まで薄くすることが困難なことが挙げられる。よってPtMnを用いた場合にはPtMnの膜厚としては、5nm～30nmが望ましい。さらに望ましくは、7nm～12nm程度が望ましい。PtMn\*

(実施例2) トップSF/SV (シンプルCoFeフリー層)

Ta5/Cux/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (8-1)

Ta5/Cux/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (8-2)

本実施例においては、フリー層として、(実施例1)のようなNiFe/CoやNiFe/CoFeのような積層フリー層ではなく、CoFe単層からなるシンプルなフリー層構成を用いた。つまり図1において、フリー層102が単層膜のCoFeからなり、高導電層101が単層膜Cuからなる構造である。

【0187】(5nmT in NiFe)を実現するような極薄フリー層を実現するには、様々な困難な点が 30 生じてくるが、単層からなるCoFe系フリー層では極薄域での軟磁性制御が膜構成が単層なことから比較的容易というメリットがある。CoFeに第3の添加元素として、B、Cu、Al、Rh、Pd、Ag、Ir、Au、Pt、Ru、Re、Osのようなものを添加しても構わない。しかし、CoFe合金のかわりにピュアなCoでは軟磁性が実現できない。CoFeはCo<sub>85</sub>Fe<sub>15</sub>at%～Co<sub>96</sub>Fe<sub>4</sub>at%が望ましい。後に述べるように、これは磁歪制御という観点からによる。

【0188】また、CoFeフリー層は軟磁性という観点からfcc(111)配向していることが望ましい。スピニフィルター効果を効果的に得るという点からも抵抗が小さくなるようにfcc(111)配向してことが好ましいが、CoFeBのような微結晶構造やアモルファス構造のフリー層の実施例も考えられる。

【0189】シンプルCoFeフリー層はMsがNiFeよりも大きいことから同じMs\*tを実現するにも薄い膜厚で実現できることから、スピニフィルター効果の観点から有利となる。例えば4.5nmTのフリー層を実現するにはNiFe/CoFeでは、NiFe3. 50

\*の場合にも、(7-4)のような、フリー層の下地の二層化に対する考え方は全く同様である。

【0184】(7-1)～(7-4)の実施例のバリエーションとして、反強磁性膜の上にさらに貴金属元素膜を積層することが考えられる。例えば、Cu、Ru、Pt、Au、Ag、Re、Rh、Pdなどの単層膜もしくは積層膜を用いてもよい。この構成によって薄いスペーサ膜厚のときでも低H<sub>in</sub>を実現できる。ただし、あまり膜厚が厚くなると、電流分流比がフリー層の上層側で多くなってしまうので、単層膜もしくは積層膜のトータル膜厚としては0.5nm～3nm程度が好ましい。

【0185】図15に関して前述したように、本実施例のスピニバルブ膜は、比較例1～4と比べて、バイアスポイントの制御性ははるかに優れ、最適なバイアスポイントを確実に得ることができる。

【0186】また、図16に関して前述したように、本実施例のスピニバルブ膜は、比較例1～4と比べて高いMR変化率を得ることができる。

6/CoFe0.5(nm)でトータル膜厚が約4nmとなるのに対し、シンプルCoFeフリー層ではCoFe2.5nmであり、NiFe/CoFeよりも約1.5nm薄くできる。この両者の膜にフリー層の下に接して高導電層を設けると、ダウンスピン電子は両者の膜ともダウンスピンの平均自由行程の値である約1nmと比べて厚いためフィルタアウトされるが、NiFe/CoFeのトータル膜厚4nm程度になるとアップスピンの平均自由行程と近い値になってくるため、その下の高導電層は単純なシャント効果をもたらすことになり、高導電層を厚くすればするほどシャント効果の影響でMRが低減してしまう。

【0190】一方、シンプルCoFeに関しては、2.5nmよりも平均自由行程が長いので、ある程度の膜厚までは高導電層をつけるほどアップスピンの平均自由行程が長くなり、MRが上昇する。経験的には高導電層にCuを用いた場合には、Cu層とNiFe/CoFe、もしくはCoFe層からなるフリー層のトータル膜厚が4nm程度、もしくは3nm～5nmのときにMRピークをとることが実験的に得られている。つまり、バイアスポイント設計上必要な高導電層膜厚があった場合、NiFe/CoFeではスピニフィルター効果というよりもシャント効果のためMRの減少をもたらすが、CoFeではスピニフィルター効果によって、バイアスポイント調整とともにMR上昇効果の両立をはかることができるので、有利となる。これは上述のように、高導電層とフリー層とのトータル膜厚でMRピーク値がきまるので、CoFe膜厚が薄いほど、MRピークをとるCu層

の膜厚が厚くなることになり、スピントラップ効果とバイアスポイント調整効果の兼用効果がでてくる。以上の理由により単純CoFeフリー層のほうがスピントラップ効果では望ましい。

【0191】積層NiFe/CoFeのほうがMR耐熱性が悪いので、単純CoFeフリー層のほうがMRが大きいのでよい。

【0192】磁歪制御も極薄層の積層膜であるNiFe/CoFeよりもCoFeの単層のほうが制御が容易。特に、極薄フリー層では界面磁歪が重要であるので、界面が一つ増えるNiFe/CoFeのほうが不利である。

【0193】(8-1)の構成でのバイアスポイントも、実施例1の場合とほぼ同様に30~50%の良好な範囲内になる。ハイト依存性も実施例1と同様に小さい。

【0194】フリー層の $M_s \cdot t$ 依存性に関しては、 $M_s \cdot t$ が小さいほどトランスファーカーブ上の飽和磁界 $H_s$ が小さくなっていくため、より厳密なバイアスポイント調整が要求される。具体的には電流磁界をより低減させることが重要になってくるので、高導電層の膜厚を増加させる必要が出てくる。本発明によるスピントラップ膜では既に述べたようにフリー層の膜厚が薄くなるほどスピントラップ効果によりMRピークが出現する高導電層の膜厚が厚いほうにシフトするため、そのトレンドとも一致しており、本発明のスピントラップ膜の設計思想が高密度用ヘッドの膜として利にかなっていることがわかる。

【0195】具体的には、フリー層 $M_s \cdot t \sim 4.5 \text{ nT}$ 、CoFe膜厚 $2.5 \text{ nm}$ のときには高導電層の良好な膜厚はCu換算で $0.5 \text{ nm} \sim 4 \text{ nm}$ 、さらに望ましくは $1 \text{ nm} \sim 3 \text{ nm}$ 、 $M_s \cdot t \sim 3.6 \text{ nT}$ 、CoFe膜厚 $2 \text{ nm}$ のときにはCu換算で、 $1 \text{ nm} \sim 4.5 \text{ nm}$ 、さらに望ましくは $1.5 \sim 3.5 \text{ nm}$ 、 $M_s \cdot t \sim 2.7 \text{ nT}$ 、CoFe膜厚 $1.5 \text{ nm}$ のときにはCu換算で、 $1.5 \text{ nm} \sim 5 \text{ nm}$ 、さらに望ましくは $2 \text{ nm} \sim 4.5 \text{ nm}$ 、 $M_s \cdot t \sim 1.8 \text{ nT}$ 、CoFe膜厚 $1 \text{ nm}$ のときにはCu換算で、 $2 \text{ nm} \sim 5.5 \text{ nm}$ 、さらに望ましくは、 $2.5 \text{ nm} \sim 5 \text{ nm}$ 程度とする。

【0196】(8-1)では反強磁性膜としてIrMnを用いているのに対し、(8-2)ではPtMnを用いている。PtMnを用いることにより、さらにMR耐熱性が向上し、出力の向上がはかれるというメリットが得られる。これは、NiFe/Co(Fe)フリー層のときと同様である。ただし、PtMnを用いたときのほうが $H_{in}$ が上昇しやすいという問題点があるため、バイアスポイントを良好なところに設計するためには、IrMnを用いたときよりも、電流磁界 $H_{cu}$ を低減させるか、 $H_{pin}$ を増加させるかの、どちらかもしくは両者の対策

が必要である。 $H_{cu}$ を低減させるためには、高導電層の $\sigma t$ を増加させる、つまり高導電層の膜厚を増加させることが考えられる。また、 $H_{pin}$ を増加させるには、シンセティックAFの上下のピン層膜厚差をIrMnのときよりも大きめにすることが考えられる。しかし、高導電層の膜厚を増加させることは $\Delta R_s$ の低下を招くことにもなるので、IrMnのときよりも高導電層膜厚でCu換算で $0 \sim 2 \text{ nm}$ 程度の範囲での調整が望ましい。また、シンセティックAF構造の $\Delta t$ を増加させることはこれまでのべてきたようにバイアスポイントのMRハイト依存性を増加させることにもなるのであまり大きくすることは望ましくなく、IrMnのときと比べてCoFe換算で $0 \sim 1 \text{ nm}$ 程度の増加で設計することが望ましい。(8-1)、(8-2)のバリエーションとして、次のような構成も考えられる。Ta5/Rux/Cuy/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (8-3) Ta5/Rux/Cuy/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (8-4) この構成においては、高導電層として、Cu単層ではなく、Ru/Cuという積層膜で構成した。積層膜にする理由は次の二つの理由による。

【0197】1. CoFe磁歪制御

2.  $H_{in}$ 低減効果

上記1.のCoFe磁歪制御に関しては、後に詳述するように、CoFeの歪み制御によって磁歪を制御しようとするものである。つまり、単純CuよりもCoFeのfcc-d(111)面間隔を広げて、Co<sub>90</sub>Fe<sub>10</sub>(atmic%)フリー層を用いたときには負側に大きくなりやすいCoFeフリー層の磁歪を、ゼロ近傍に制御しようとするものである。よって、Cu層の下に位置する材料としてはCuよりも原子半径が大きいものが望ましい。例えば、Ruの他に、Re、Au、Ag、Al、Pt、Rh、IrあるいはPdなどが望ましい。磁歪制御という意味では下地二層化の他にCoFe組成を90-10から変えることによって可能である。具体的には、Co<sub>90</sub>Fe<sub>10</sub>~Co<sub>96</sub>Fe<sub>4</sub>の組成範囲のCoFe合金フリー層が用いられる。一方、上記2.の $H_{in}$ 低減効果に関しては、膜成長のときの平坦性を向上させる効果がRuにはあるからである。既に述べてきたように、 $H_{in}$ はできるだけ小さいところで $H_{cu}$ と $H_{pin}$ によってバイアスポイント設計することが望ましいからである。特に、SFSVではMRのスピントラップ効果、フリー層の上層のシャント低減という2つの点でスペーサ厚はできるだけ薄いほうが望ましく、Cu~2nm程度の極薄スペーサを使いこなす技術が必要なので、一般的にスペーサ厚依存性が大きな $H_{in}$ 制御が困難になる。Ru/Cu積層膜にすることによって、Ru1.5nm/Cu1nm~2nm下地、フリー層 $M_s \cdot t$ 3.6nT、CoFe膜厚2nmという極薄フリー層、スペーサCu2nmというもので、 $H_{in}$ として7~13Oeという低 $H_{in}$ を実現することができる。(7-1)、(7

−2)の実施例においては $H_{in}$ が200e程度であったことを考慮すると、この $H_{in}$ 低減効果は大きい。

【0198】 $H_{cu}$ 計算という観点からみたときには、Ruの比抵抗から $\sigma t$ とCu膜厚に換算すればよいだけである。実験的に求まったRuの比抵抗は $30 \mu\Omega cm$ なので、 $\sigma t$ のシャント効果としては比抵抗 $10 \mu\Omega cm$ のCu膜厚にして1/3の膜厚ということになる。例えば、Ru1.5nm/Cu1nmという構成ではシャントのCu膜厚換算値で $(1.5nm/3) + 1nm = 1.5nm$ と同等ということになる。

\*10

(実施例3) ボトムSFSSV (NiFe/Co(Fe)フリー層)

Ta5/Ru2/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu2/Ta5 (9-1)

Ta5/Ru1/NiFeCr2/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu2/Ta5 (9

−2)

反強磁性膜がフリー層よりも下層側に位置する、いわゆるボトムタイプの実施例について示す。図6は、本実施例にかかるスピバルブ膜構成を表す概念図である。すなわち、下地バッファ層131上に、反強磁性膜結晶制御層128、反強磁性膜127が積層され、ピン層126、124が層125を介して反強磁性的に結合している。層124上にスペーサ層123、フリー層122、非磁性高導電層121が順次積層され、最後にキャップ層132が設けられている。

【0200】(9-1)の実施例は、反強磁性膜結晶制御層128が単層Ruからなり、127の反強磁性膜がPtMn、フリー層122が129、130の二層の積層膜から形成された場合である。(9-2)の実施例は、反強磁性膜結晶制御層128が133の膜としてRu、134の膜としてNiFeCrの二層膜から形成され、127の反強磁性膜がIrMn、フリー層が129、130の二層膜から形成された場合の実施例である。

【0201】ボトムタイプのスピバルブ膜においては、Ta等のバッファ層の上にさらに反強磁性膜結晶制御層として、fccまたはhcpの下地膜を1nm〜5nm程度用いる。例えば、Cu、Au、Ru、Pt、Rh、Ag、Ni、NiFeやそれらの合金膜、積層膜などが用いられる。これらのシード(seed)層は反強磁性膜としての機能を高めるために重要な膜である。(9-1)のPtMnの実施例においては単層のRu層を、(9-2)のIrMnの実施例においては、Ru/NiFeCrの積層膜を用いた。この反強磁性膜結晶制御層は反強磁性膜のブロッキング温度を充分高い値にすること、および膜平坦化を促し、本発明で必要とされる1.5nm〜2.5nm程度の極薄スペーサを用いた場合でも低 $H_{in}$ を実現する働きがある。

【0202】本発明によるバイアスポイントメリットという点では、上記実施例程度の膜厚の範囲では、このシード層の種類によって、大きな影響を受けることはない。ただし、低抵抗材料、すなわち比抵抗の小さな材料

\*【0199】また(8-1)〜(8-4)の実施例のバリエーションとして、反強磁性膜の上にさらに貴金属元素膜を積層することが考えられる。例えば、Cu、Ru、Pt、Au、Ag、Re、Rh、Pdなどの単層膜もしくは積層膜を用いてもよい。この構成によって薄いスペーサ膜厚のときでも低 $H_{in}$ を実現できる。ただしあまり膜厚が厚くなると、電流分流比がフリー層の上層側で多くなってしまうので、単層膜もしくは積層膜のトータル膜厚としては0.5nm〜3nm程度が好ましい。

を用いることは好ましくない。これは、ここでシャント分流通層が増えてしまうと、電流中心をフリー層に近づけることが困難になるからである。よって、反強磁性膜としての機能を高められる材料の範囲でできるだけ高抵抗の材料を用いることが好ましい。例えば、低抵抗のNiFeの代わりに、NiFeにCr、Nb、Hf、W、Ta等を添加して比抵抗を上げて用いる実施例が考えられる。(9-2)ではNiFeの代わりにNiFeCrを用いている。

【0203】反強磁性膜としては、(9-1)ではPtMn、(9-2)ではIrMnを用いている。PtMnを用いるメリットとしては、ブロッキング温度が高温であること、および $H_{u.a.}$ が大きいこと、およびプロセス熱処理後のMR熱劣化が非常に小さく、高MR、高 $\Delta R_s$ が実現できることが挙げられる。トップタイプの場合と同様に極薄フリー層を用いた場合に高いMRをプロセス熱処理後に維持できるという点から貴金属を含む反強磁性膜であるPtMnを用いるメリットは非常に大きい。PtMnの代わりにPdPtMnを用いても良い。好ましい膜厚範囲としては、5nm〜30nm、さらに好ましくは、7nm〜12nmが良い。

【0204】(9-2)のIrMnを用いるメリットとしては、PtMnよりも薄膜領域で特性がでるため、高密度化に対応した狭ギャップヘッドに適しているという点を挙げることができる。IrMnの膜厚としては3nm〜13nmが望ましい。IrMnも貴金属元素Irを含む反強磁性膜であるため、MR変化率の耐熱性に優れている。IrMnの代わりに同様に貴金属元素を含むRuRhMnを用いてもよい。

【0205】上記のように、反強磁性膜としては、PtMn、IrMn、PdPtMnが最も好ましいが、本発明のスピバルブ膜のバイアスポイントメリットという点では反強磁性膜材料によって限定されるものではなく、NiO、CrMnPt、NiMn、 $\alpha\text{-Fe}_2\text{O}_3$ 等のその他の反強磁性膜を用いても構わない。

【0206】シンセティックピン層の二層の強磁性材料

としては、ここではCoFe合金層を用いたが、Co、NiFe、またはNiFeと、CoもしくはCoFeの積層膜を用いても構わない。これらの構成材料や膜厚等の考え方は、前述した実施例1、2のトップタイプの場合と全く同様である。本発明の重要なポイントであるこのシンセティックピン層の構成は、前述のように、ピン漏洩磁界を低減させることが最も大きな目的であり、この上下強磁性層の $M_s \cdot t$ 差はフリー層に接して設けられる高導電層の膜厚と密接に関連して変えられるものである。

【0207】スペーサについてもトップタイプのときと考え方は変わらず、できるだけ薄いほうが好ましい。具体的には、1.5nm～2.5nm程度が望ましく、さらに望ましくは、1.8nm～2.3nmが好ましい。

【0208】フリー層としては、ここでの実施例ではNiFe/Coの積層膜を用いている。このフリー層の膜厚、材料の考え方もトップタイプのときとほぼ同様である。ただし、NiFeの下地膜がトップタイプと、ボトムタイプの場合では異なるため、低磁歪実現のためのNiFeの組成がトップタイプのときとは若干異なる。具体的にはNiFe/CoFe積層フリー層の場合には、NiFeの低膜厚化に伴うNiFe/CoFe積層フリー層の磁歪の正側へのシフトがトップタイプのときよりも小さいので、トップタイプのときよりもNiFeの組成としてNiプアのもののでも最適磁歪を実現できる。

【0209】例えば、NiFe3nm/CoFe0.5nm積層フリー層の場合にはトップタイプではNiFeの組成として、Ni<sub>81</sub>Fe<sub>19</sub>(at%)ではまだ正側に大きい値となって使用不可能だが、ボトムタイプではNi<sub>81</sub>Fe<sub>19</sub>(at%)で小さな正の磁歪値となって実用上問題ない膜となる。

【0210】本発明の大きなポイントの2点目である高\*

Ta5/Ru/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu1.5/Ru1.5/Ta5 (9-3)

Ta5/Ru/NiFeCr/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu1.5/Ru1.5/Ta5 (9-4)

上記膜構成において、Cu薄膜の比抵抗 $10 \mu\Omega \text{cm}$ に対して、Ruは $30 \mu\Omega \text{cm}$ なので、電気的なシャント効果としては、Cu1nmに対し、Ru3nmが同等の効果をもたらすことになる。つまり、上記(9-3)、(9-4)の膜においては、高導電層の膜厚はCu換算で2nmと同等ということになる。Cu単層の場合に0.5nm～3nmまでの範囲で用いられるので、Ruも同様に0.5nm～6nmの範囲で用いられる。ただし、Ruでは比抵抗も高くスピントラップ効果はCuの場合よりも弱いため、CoFeに接する高導電層としては、Cuのほうが好ましく、また、Ruをあまり厚くすることは狭ギャップという点からも好ましくないの、CoFeに接しさせてCuなどを用い、Cu膜厚は0.5nm～2nm程度用いた上で、2層の他の金属材

\*導電層としては、ここではCu膜が用いられている。この高導電層の最も大きな役割は、電流センターをできるだけフリー層に近づけて電流磁界を低減させることである。

【0211】さらに別の効果として、Cu導電層によるMRのスピントラップ効果も用いているため、極薄フリー層を用いているにも関わらずMR変化率の劣化はない。

【0212】最適なCu膜厚の範囲はトップSFVのときと同様であり、フリー層厚、シンセティックAFの上下のピン層膜厚差によって最適値が微妙にずれることもトップタイプのときと同様である。またCuキャップ層のバイアスポイント調整、高MR変化率維持以外の別の大きな効果として、極薄フリー層での低 $H_{in}$ を実現できることにある。例えば、同じフリー層厚でCuキャップがない場合には $H_{in}$ が300e以上あったものがCuキャップを用いることにより約100eまで低減できる。

【0213】ここで、(9-1)、(9-2)のバリエーションとして、フリー層CoFeに接した高導電層Cuの代わりに、二層以上の積層膜からなる高導電層で構成したもよい。例えば、Cu/Ru、Cu/Re、Cu/Rh、Cu/Ptなどが挙げられる。二層にする効果としては、トップタイプのときに記述したようにCoFeフリー層の磁歪は歪みによって影響を受けるので、磁歪 $\lambda_s$ を調整することが主な目的である。また、低 $H_{in}$ を実現することが本発明においては重要だが、低 $H_{in}$ 制御目的のためにも、2層にすることがある。

【0214】具体的な膜構成としては、以下のようなものが考えられる。

【0215】

料を用いることが好ましい。

(実施例4) ボトムSFV (CoFeフリー層)

Ta5/Ru2/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu2/Ta5 (10-1) Ta5/Ru1/NiFeCr2/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu2/Ta5 (10-2) 本実施例は、図2に例示したボトムタイプに属するもので、フリー層122の代わりに単層膜のCoFe層が用いられているタイプのものである。それ以外は、前述した実施例3と同様である。フリー層以外の層の材料、膜厚の考え方は全く実施例3と同様である。CoFeフリー層を用いるメリットは、トップタイプのときと同様である。さらに、この実施例では $M_s \cdot t$ がNiFe換算で3.6nmTのときだが、 $M_s \cdot t \sim 4.5 \text{nmT}$ と比較すると、CoFe単層フリー層ならば膜厚2.5nm

で薄くスピンフィルター効果が得られるのに対して、 $\text{NiFe}/\text{Co}(\text{Fe})$ だと $\text{NiFe}_4/\text{CoO}_{0.5}(\text{nm})$ と総膜厚が厚くなり、高導電層を設けることによるMRのスピンフィルター効果は得られず、単純シャント層となること、および $\text{NiFe}$ 自体のシャント効果もあることから、 $\Delta R_s$ で $\text{CoFe}$ 単層フリー層と比較して、0~30%減少する。

【0216】以上のことから、 $M_s \cdot t$ の広い範囲で $M_s \cdot t$ のスピンフィルター効果が得られることから、 $\text{CoFe}$ フリー層の実施例である本実施例のほうが、実施例3の場合よりも望ましい。

Ta5/NiFe/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu1.5/Ru1.5/Ta5 (10-3)

Ta5/NiFe/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu1.5/Ru1.5/Ta5 (10-4)

上記のような積層膜非磁性高導電層によって $\text{CoFe}$ の磁歪を制御する方法以外に、 $\text{CoFe}$ の組成を変えることによる磁歪制御もある。一般的に、フリー層に加わる歪調整は下地膜のほうがやりやすいが、ボトムタイプではフリー層の下側での材料は自由に選ぶことは困難となるからである。ボトムタイプのときには $\text{Cu}$ 上に $\text{CoFe}$ が積層されることになり、そのときには $\text{Co}_{90}\text{Fe}_{10}(\text{at}\%)$ を用いると、負側の大きな磁歪になりやすい。それを正側にシフトさせるために、 $\text{Co}$ リッチの $\text{CoFe}$ を用いることが望ましい。具体的には、 $\text{Co}_{90}\text{Fe}_{10} \sim \text{Co}_{96}\text{Fe}_4(\text{at}\%)$ の $\text{CoFe}$ フリー層を用いることが望ましい。しかし $\text{Co}$ リッチにして $hcp$ 相が混在してしまうと、フリー層の軟磁性が劣化( $H_c$ が増大)するので、 $\text{Co}_{98}\text{Fe}_2$ のような $\text{Co}$ リッチすぎる $\text{CoFe}$ 合金を用いることは望ましくない。

【0218】上記の膜構成において、 $\text{Cu}$ 薄膜の比抵抗 $10 \mu\Omega\text{cm}$ に対して、 $\text{Ru}$ は $30 \mu\Omega\text{cm}$ なので、電気的なシャント効果としては、 $\text{Cu} 1 \text{ nm}$ に対し、 $\text{Ru} 3 \text{ nm}$ が同等の効果をもたらすことになる。つまり、上記(10-3)、(10-4)の膜においては、高導電層の膜厚は $\text{Cu}$ 換算で $2 \text{ nm}$ と同等ということになる。 $\text{Cu}$ 単層の場合に $0.5 \text{ nm} \sim 3 \text{ nm}$ までの範囲で用いられるので、 $\text{Ru}$ も同様に $0.5 \text{ nm} \sim 6 \text{ nm}$ の範囲で用いられる。ただし、 $\text{Ru}$ では比抵抗も高くスピンフィルター効果は $\text{Cu}$ の場合よりも弱いので、 $\text{CoFe}$ に接する高導電層としては、 $\text{Cu}$ のほうが好ましく、また、 $\text{Ru}$ をあまり厚くすることは狭ギャップという点からも好ましくないため、 $\text{CoFe}$ に接しさせて $\text{Cu}$ などを用い、 $\text{Cu}$ 膜厚は $0.5 \text{ nm} \sim 1 \text{ nm}$ 程度用いた上で、2

\*【0217】ここで、(10-1)、(10-2)のバリエーションとして、フリー層 $\text{CoFe}$ に接した高導電層 $\text{Cu}$ の代わりに、二層以上の積層膜からなる高導電層で構成したもよい。例えば、 $\text{Cu}/\text{Ru}$ 、 $\text{Cu}/\text{Re}$ 、 $\text{Cu}/\text{Rh}$ などが挙げられる。二層にする効果としては、既述のように $\text{CoFe}$ フリー層の磁歪は歪みによって影響を受けるので、磁歪 $\lambda_s$ を調整することが主な目的である。また、低 $H_{in}$ を実現することが本発明においては重要だが、低 $H_{in}$ 制御目的のためにも、2層にする必要がある。具体的な膜構成としては、以下のようなものが考えられる。

層の他の金属材料を用いることが好ましい。

(第2~第6の実施の形態：高温安定性と再生出力の向上)次に、高温安定性と再生出力の向上の観点からみた本発明の第2~第6の実施の形態に関して説明する。

【0219】まず、第2~第6の実施の形態に共通な技術的思想に関して概説する。

【0220】図17は、本発明の第2~第6の実施の形態のうちの一実施の形態を示す図である。図17において、基板10に下シールド11、下ギャップ膜12を設け、その上にスピンバルブ素子13が形成されている。スピンバルブ素子はスピンバルブ膜14と一対の縦バイアス膜15および一対の電極16から構成され、さらに非磁性下地層141、142、反強磁性層143、磁化固着層144、中間層145、磁化自由層146、保護膜147が形成されている。

【0221】表6には本発明の実施の形態の $\text{SyAF}$ を磁化固着層に用いた場合の、 $\text{SyAF}$ の強磁性層と結合する反強磁性層の材料組成および膜厚と、 $200^\circ\text{C}$ における交換結合定数 $J$ 、交換バイアス磁界 $H_{UA}^*$ および $H_{UA}$ 、ブロッキング温度 $T_b$ 、およびスピンバルブ素子の抵抗変化率 $\Delta R/R$ を示す。また表7には、磁化固着層として従来の単層の磁化固着層を用いた場合の同様の表を示す。また表8には $\text{SyAF}$ と結合した反強磁性層の最密面からの回折線ピークのロッキングカーブ半値幅 $\Delta\theta$ と $200^\circ\text{C}$ における $\text{SyAF}$ の反強磁性層側強磁性層との交換結合定数 $J$ およびブロッキング温度 $T_b$ との関係を示す。

【0222】

【表1】

表 8

スピバル膜構成:

基板/Ta (5nm)/NiFe/CoFe/Cu (3nm)/CoFe (2.5nm)  
 /Ru (0.9nm)/CoFe (2.5nm)/反強磁性層/Ta (5nm)

反強磁性層 材料	膜厚 (nm)	200℃における J (erg/cm <sup>2</sup> )	200℃における H <sub>0A</sub> ' (Oe)	ブロッキング 温度 T <sub>b</sub> (℃)	抵抗変化率 ΔR/R (%)
Ir22Mn78  (比較例)	5	0.04	400	250	7.3
	7	0.045	450	270	7.3
	10	0.045	450	290	7
	20	0.04	400	300	6.5
	30	0.035	350	300	5.5
Rh20Mn80	7	0.025	250	235	7.1
	10	0.035	350	260	6.8
Rh14Ru7Mn79	7	0.02	200	225	7.2
	10	0.03	300	245	6.8
Pt53Mn47  (比較例)	10	0.02	250	290	7.9
	15	0.025	400	320	7.4
	20	0.1	>600	350	7
	30	0.12	>600	370	6.2
Ni50Mn30	15	0.02	250	300	6.8
CrMnPt	15	0.02	200	240	6.9

IrMn, RhMn, RhRuMn, CrMnPtを用いたスピバル膜:

270℃、1時間の熱処理を施した後の結果

PtMn, NiMnを用いたスピバル膜:

270℃、10時間の熱処理を施した後の結果

【0223】

\* \* 【表2】

表 7

スピバル膜構成:

基板/Ta (5nm)/NiFe/CoFe/Cu (3nm)/CoFe (2.5nm)  
 /反強磁性層/Ta (5nm)

反強磁性層 材料	膜厚 (nm)	200℃における J (erg/cm <sup>2</sup> )	200℃における H <sub>0A</sub> ' (Oe)	ブロッキング 温度 T <sub>b</sub> (℃)	抵抗変化率 ΔR/R (%)
Ir22Mn78	5	0.04	170	250	6.6
	10	0.045	190	290	6.2
Pt51Mn49	10	0.03	130	300	7.2
	20	0.1	430	350	6.7
	30	0.12	510	370	6.4

IrMnを用いたスピバル膜: 270℃、1時間の熱処理を施した後の結果

PtMnを用いたスピバル膜: 270℃、10時間の熱処理を施した後の結果

【表3】

【0224】

表 8

反強磁性層 材料 膜厚 (nm)		最密面ピークのロッキング カーブ半値幅 $\Delta\theta$ (°)	200℃における J (erg/cm <sup>2</sup> )	プロッキング 温度 T <sub>b</sub> (°C)
Ir <sub>22</sub> Mn <sub>78</sub>	5	12	0.01	210
	5	8	0.025	230
	5	5	0.045	250
	5	3	0.05	250
Rh <sub>20</sub> Mn <sub>80</sub>	7	13.5	~0	190
	7	8	0.02	225
	7	4	0.025	235

本発明者は表6および表8に示すように、1) 反強磁性層と結合する磁化固着層をSyAFによって構成し、反強磁性層の組成を選べば温度200℃における交換結合定数Jとして0.02 erg/cm<sup>2</sup>以上を得ることができること、2) 反強磁性層の最密面ピークのロッキングカーブ半値幅が小さくなるように最密面を配向させて、ロッキングカーブ半値幅が好ましくは8°以下、さらに好ましくは5°以下となるようにすることによって、温度200℃における交換結合定数Jを高めることができること、3) 反強磁性層の磁気膜厚を20nm以下、より好ましくは10nm以下とすることにより、抵抗変化率を単層の磁化固着層を用いて構成したスピバルブ素子の抵抗変化率と同等以上に高めることができること、そして4) 温度200℃における交換結合定数Jを0.02 erg/cm<sup>2</sup>以上にすることにより、温度200℃において交換バイアス磁界H<sub>UA</sub>\*を200Oe以上にすることができ、記録媒体などから再生素子のスピバルブ素子に加わる最大磁界が200Oeであっても安定な磁化固着層が得られること、を見出して本発明をなすに至った。

【0225】図18は外部磁界に対するスピバルブ膜の抵抗値の変化と、交換バイアス磁界H<sub>UA</sub>\*を示す模式図である。図18で交換バイアス磁界H<sub>UA</sub>\*は、実質的に磁化固着層の磁化が動かない磁界の最大値を、低磁界側の直線部の延長線と高磁界側の直線部の延長線との交点として求めた磁界の値と定義される。交換バイアス磁界H<sub>UA</sub>\*として200Oe以上を有する磁化固着層は、磁化固着方向に外部磁界を加えた場合の抵抗-磁界特性において、200Oeまでの磁界範囲では、磁化がほとんど動くことがなく、磁化自由層のみが磁化応答した抵抗変化が得られる。

【0226】図18では、磁界センサとしての動作点である磁界がゼロの近傍で磁化自由層の磁化応答に伴う急峻な抵抗変化のみが、抵抗-磁界特性を示す曲線上に認められ、200Oeまでの外部磁界に対しては、この磁化自由層の磁化応答以外には抵抗の変化が認められず、磁化自由層が飽和した後は、磁界に対する実質的な応答がないことを示す。

【0227】従来のNiO反強磁性層や、FeMnCr

反強磁性層を用いた場合には、200℃においてはほとんどJが得られない。また、30nm厚のCrMnPt反強磁性層を用いた場合には抵抗変化率が従来の単層の磁化固着層よりも低くなってしまうので好ましくない。

【0228】従来の単層の磁化固着層においては、表7に示されているように、PtMnを用いた場合には20nm厚以上で高いH<sub>UA</sub>が得られるが、その場合の抵抗変化率は6.4~6.7%と比較的低い値を示す。

【0229】これに対し、表6に示す本発明の実施の形態によれば、IrMn、RhMn、RhRuMn、PtMn、NiMn、CrMnPtなどの厚さ20nm以下の反強磁性層を用いることにより、200℃にてH<sub>UA</sub>\*が200Oe以上の優れた耐熱性を満足し、しかも抵抗変化率は従来の単層の磁化固着層を用いた場合と同等あるいはそれ以上の値が得られる。なお本発明において反強磁性層の厚さの下限は好ましくは3nm以上である。

【0230】図19はH<sub>UA</sub>\*が200Oeの本発明の実施形態のスピバルブ膜、および従来のH<sub>UA</sub>が500Oeの単層磁化固着層のスピバルブ膜について、200℃にて200Oeの模擬バイアス磁界を与えた場合の経過時間と磁化固着層の磁化の動いた角度との関係を示す。図19に示されているように、従来の単層磁化固着層のスピバルブ膜に比べて、本発明の実施形態のスピバルブ膜は、200℃におけるH<sub>UA</sub>\*が200Oeと、単層磁化固着層のH<sub>UA</sub>、510Oeに比べて小さいにもかかわらず、200℃における固着磁化の経時変化はわずかであって、安定性に優れることがわかる。

【0231】また、IrMn、RhMn、RhRuMnなどのMnリッチのγ-Mn系反強磁性体膜を用いた場合にみられるように、10nm以下の反強磁性層厚では、従来の単層の磁化固着層を用いた場合よりも大きい抵抗変化率が得られ、さらに好ましい。

【0232】また、表6の本発明の実施の形態においては、T<sub>b</sub>が240~300℃の範囲の反強磁性層で良好な固着磁化の耐熱性を示す。従ってT<sub>b</sub>近傍では磁気結合層の結合磁界を上回る大きな磁界を加えて強磁性体層Aと強磁性体層Bを同方向に飽和させることにより、磁化固着層の磁化方向を外部磁界により自由に制御できるので、磁気結合層と強磁性層Aおよび強磁性層Bとの間

の拡散があまり問題とならない300℃以下での磁化固着処理が可能となる。

【0233】磁気結合層と強磁性層Aおよび強磁性層Bとの間の拡散や拡散の影響を防止するには、磁気結合層として厚さが0.8nmを超えることが好ましく、またRu、Rh、Cr、Irなどを用いることが好ましい。また強磁性層Aや強磁性層Bには、CoFeなどのCo合金を用いること、磁気結合層の凹凸を磁気結合層の厚みと同等かそれ以下に抑えることが有効である。

【0234】さらに、磁化固着層の磁化方向規定熱処理では、強磁性層Aと強磁性層Bを同方向に飽和させる必要があるため、強磁性層Aや強磁性層Bの膜厚が2nm程度まで薄くなると、磁気結合層厚が0.8nm以下の場合には磁気結合層の反強磁性的結合磁界が約7kOeまたはそれ以上に増大し、実用的な外部磁界で磁化固着層の磁化方向規定熱処理が困難になってしまう。このため磁気結合層厚は0.8nmを超える厚さにした方が、実用的な外部磁界例えば7kOeで磁化固着層の磁化方向規定熱処理が可能であって好ましい。

【0235】表6の本発明の実施の形態において採用しているSyAF磁気結合層においては、CoFe合金で構成された強磁性層Aおよび強磁性層Bの厚みが2.5nm、Ruで構成された磁気結合層の厚み0.9nmとすることにより、反強磁性結合磁界は約4kOeであり、この程度の反強磁性磁界で磁化固着層の耐熱性確保を十分に良好に行うことができる。

【0236】本発明においては、強磁性層Aと強磁性層Bの磁性膜厚がほぼ等しいか、あるいは強磁性層Aの磁気膜厚が強磁性層Bの磁気膜厚よりも厚い構成が好ましい。強磁性層Aと強磁性層Bの磁性膜厚がほぼ等しい場合には、強磁性層Aの磁気膜厚が強磁性層Bの磁気膜厚よりも厚い場合に比べて、媒体磁界や縦バイアス磁界に対して磁化固着層の磁化が著しく安定である。

【0237】一方、強磁性層Aの磁気膜厚が強磁性層Bの磁気膜厚よりも大きい場合には、強磁性層Aと強磁性層Bの磁性膜厚がほぼ等しい場合に比べて、ESDによる固着磁化反転のない良好なESD特性が実現できる。この場合、強磁性層Aの磁気膜厚に対する強磁性層Bの磁気膜厚の比が0.7~0.9の範囲とすることが好ましい。例えば強磁性層Aに2.5nmのCoFe合金、強磁性層Bに2nmのCoFe合金とすることが好ましい。強磁性層Aと強磁性層Bの磁性膜厚がほぼ等しい場合でも、磁気ディスクドライブに電流によって磁化固着層の磁化を所定の方向に再固着する回路を組み込む（例えば米国特許第5650887号）ことによって、ESDによる固着磁化反転が生じて再固着できるドライブが実現できる。200℃におけるJの値が0.02erg/cm<sup>2</sup>以上を実現するには、Mnを主成分とする、IrMn、RhMn、RhRuMnなどからなる $\gamma$ -Mn相、あるいはAuCuII形の規則化相を主相とする反

強磁性層（Mnの組成が0を超えて40%未満で実現し易い）を、あるいはPtMn、PtPdMn、NiMnなどからなる面心正方晶の規則化相（CuAuI型）を含む反強磁性層（Mn組成が40%以上70%以下で実現し易い）を、あるいはCrMnやCrAlなどのCr系反強磁性層を用いることが好ましい。

【0238】さらにこれらの合金で200℃におけるJの値が0.02erg/cm<sup>2</sup>以上を高い抵抗変化率が得られる薄い反強磁性層にて実現するには、最密面が配向した結晶構造を実現することが必要である。

【0239】表8に示された配向度を表わすパラメータである最密面からの回析線ピークのロッキングカーブ半値幅 $\Delta\theta$ とTbおよびJの関係から、半値幅 $\Delta\theta$ が8°以下でJの値が0.02erg/cm<sup>2</sup>以上が得られ、本発明の磁気抵抗効果ヘッドが実現できることがわかる。PtMnなどの面心正方晶に規則化した反強磁性層、CrMnなどのbcc系の反強磁性層でも同様に最密面が配向すると薄い反強磁性膜厚で高Tbかつ200℃での高いJが実現できる。ここに最密面は、fcc相の場合は(111)ピークを、hcp相の場合は(002)ピークを、bcc相の場合は(110)ピークをそれぞれ意味する。また、面心正方晶からなる規則化相を含むPtMnなどの場合には、残存するfcc相が(111)面配向していること、あるいは規則化した面心正方晶の(111)面が配向していることを意味する。なおfcc相やhcp相の場合、積層欠陥を含んでもよい。

【0240】なお、図20に示すように、最密面からの回析線ピークのロッキングカーブ半値幅はヘッド断面からの透過電子顕微鏡回析像における最密面スポットの膜面垂直方向からの揺らぎによっても表現でき、X線回析によるロッキングカーブ半値幅と透過電子顕微鏡回析像の最密面スポットの揺らぎ角度は概ね一致する。

【0241】このような良好な最密面配列を実現するには、スピンバルブ膜の成膜を酸素ガスなどの不純物を極力抑制した雰囲気で行う。例えば10<sup>-9</sup>Torr台にまで予備排気ができる装置による成膜、500ppm以下に酸素含有量を抑制したスパッタターゲットを用いた成膜、基板バイアススパッタなどの方法により適度なエネルギーをスパッタ原子が基板に堆積する際に与える成膜、アルミナキャップ層とスピンバルブ膜との間に下地層、例えば、Au、Cu、Ag、Ru、Rh、Ir、Pt、Pdなどの貴金属単体あるいは合金下地層や、NiFe、NiCu、NiFeCr、NiFeTaなどのNi系合金層を設ける、などの方法がある。

【0242】以上、「耐熱性と再生出力の向上」に関する本発明の第2~第6の実施の形態に関する共通的な技術思想について概説した。

【0243】次に、本発明の第2~第6の実施の形態について詳細に説明する。

【0244】（実施の形態2）図17に本実施形態にかかる磁気抵抗効果ヘッドの一例を示す。図17においてアルチック（ $\text{Al}_2\text{O}_3 \cdot \text{TiC}$ ）基板10に下シールド11、下ギャップ膜12を形成し、その上にスピバルブ素子13を形成する。ここに下シールド11は、厚み0.5~3 $\mu\text{m}$ を有するNiFe、Co系アモルファス磁性合金、FeAlSi合金などであって、NiFeやFeAlSi合金では研磨により表面凹凸を除去することが好ましい。また下ギャップ膜12には厚み5~100nmのアルミナや窒化アルミなどが用いられる。

【0245】スピバルブ素子はスピバルブ膜14と一対の縦バイアス膜15および一対の電極16から構成される。スピバルブ膜は、Ta、Nb、Zr、Hfなどの厚み1~10nmの非磁性下地層141、必要に応じて厚み0.5~5nmの第2の下地層142、反強磁性層143、磁化固着層144、厚み0.5~4nmの中間層145、磁化自由層146、必要に応じて厚み0.5~10nmの保護膜147から構成される。

【0246】その上にギャップ層17、上シールド18が形成される。また図示していないが、さらにその上に記録部が形成される。ギャップ層17は厚み5~100nmのアルミナや窒化アルミなどが用いられ、上シールド18には厚み0.5~3 $\mu\text{m}$ を有するNiFe、Co系アモルファス磁性合金、FeAlSi合金などが用いられる。

【0247】反強磁性層143としてIrMn、RhMn、RhRuMnなどの $\gamma$ -Mn系のMnリッチ合金や、PtMn、NiMnなどの面心正方晶の規則系合金が用いられる場合には、下地層142は、Cu、Ag、Pt、Au、Rh、Ir、Niなどまたはそれらを主成分とするAuCu、CuCrなどの合金、特願平9-229736号に記載のNi、Ni系合金、NiFe、NiFe系合金など、Ru、Tiなど、またはそれらを主成分とする合金からなるhcp相金属が好ましい。

【0248】また反強磁性層143としてCr系反強磁性合金膜を用いる場合には、下地層142は、上述した下地層でもよいが、bcc層からなるCr、V、Feなど、またはそれらを主成分とする合金からなる下地層も適する。

【0249】磁化固着層144は磁気結合層1442を介して反強磁性的に結合する2層の強磁性層Bの1441と強磁性層Aの1443からなる3層膜で構成されている。強磁性層Bと反強磁性層143との中間、または強磁性層Bと縦バイアス膜の反強磁性膜との中間に酸素、窒素などの非金属を挿入すると大きな抵抗変化が得られるので好ましい。この場合、非金属を挿入する層の厚さは0.2~2nmが好ましい。例えば、強磁性層A（または強磁性層B）をその中間に酸化層を介した強磁性層A（または強磁性層B）／酸化層／強磁性層B（または強磁性層A）が好ましい。

【0250】磁気結合層1442はRu、Rh、Ir、Crからなる金属、特に大きな反強磁性結合機能を有するRuや広い膜厚範囲で反強磁性結合機能を有するRuや広い膜厚範囲で反強磁性結合機能が得られるCrが好ましい。磁気結合層の膜厚としては、文献（Phy. Rev. Lett. 67. (1991) 3598）に示されているような反強磁性結合機能を発現できる膜厚であれば使用可能である。

【0251】図21にはCoの強磁性層およびCoFe合金の強磁性層の磁気結合層に、Ruを用いた場合の熱処理後のRu厚と反強磁性結合の低下度合の関係を残留磁化比Mr/Msによって示したものである。ここにMr/Ms=1は反強磁性結合が完全に消失、Mr/Ms=0が完全な反強磁性結合であることを示す。

【0252】図21に示されたように、磁気結合層にRuを用いた場合には、磁化固着層144の磁化方向を決める熱処理やその他のヘッド工程で場合によっては必要になる250~300℃での熱処理を施しても隣接する強磁性層B、強磁性層Aと磁気結合層との相互拡散による磁気結合機能などの特性劣化を生じない0.8nmを超えて1.2nm以下が好ましい。Ru層が0.8nm以下では相互拡散による反強磁性結合機能の低下について注意を払う必要があり、他方で1.2nm厚を超えると反強磁性結合が困難になる。また磁気結合層にCrを用いた場合には、Ruを用いた場合と同様な理由で、0.8nmを超えて1.5nm以下が好ましい。そして強磁性層Bおよび強磁性層AにはCoまたはCo系合金が好ましい。

【0253】強磁性層Bおよび強磁性層Aに $\text{Co}_{1-x}\text{Fe}$ 合金（ $0 < x \leq 0.5$ ）を用いれば、IrMn、RhMn、RhRuMnなどの $\gamma$ -Mn系のMnリッチ合金からなる反強磁性層143との大きな交換結合係数が得られ、しかもRuと強磁性層Bおよび強磁性層Aとの拡散を防ぐことができるので特に好ましい。CoFe合金に代えてCoを用いる場合には、Jがおよそ2/3となり、また図21に示すように270℃、1時間保持程度の熱処理でも安定な磁気結合機能を維持できる磁気結合層の膜厚範囲がCoFe合金の場合に比べて狭くなる。

【0254】なお、磁気結合層の表面平滑性も、その反強磁性結合機能の耐熱性を維持するために重要であって、10nm<sup>2</sup>程度の膜面内の微小領域にて、磁気結合層の厚みよりも大きな表面凹凸が発生すると、反強磁性結合機能の耐熱性が劣化する。従って磁気結合層の表面凹凸の大きさは磁気結合層の膜厚以下であることが好ましい。

【0255】表9に強磁性層Aと強磁性層Bの膜厚に対するスピバルブ膜面抵抗Rs、面抵抗変化 $\Delta R_s$ および抵抗変化率 $\Delta R/R$ の変化を示す。また図22にはスピバルブ膜の磁界に対する抵抗値の変化を示す。

【0256】

【表4】

表9

スピバルブ膜の構成:

Ta/Au/CuMn/強磁性層A (CoFe)/Ru (0.9nm)  
 /強磁性層B (CoFe)/Cu (2.5nm)/磁化自由層  
 (CoFe 4nm)/Ta

熱処理: 270℃、1時間

強磁性層A 厚さ (nm)	強磁性層B 厚さ (nm)	抵抗変化率 $\Delta R/R$ (%)	表面抵抗値 $R_s$ ( $\Omega$ )	表面抵抗変化量 $\Delta R_s$ ( $\Omega$ )
7	7	7.2	7.5	0.54
5	5	8.0	9.8	0.78
3	3	8.6	12	1.03
2	2	8.4	14.1	1.18
1	1	8.0	15.3	1.22
0.5	0.5	5.9	15.6	0.92

表9から、強磁性層Bと強磁性層Aの膜厚は1~5nm  
 が大きな抵抗変化率を得るために好ましく、特に1nm  
 ~3nmの膜厚が図22に示された外部磁界に対して安  
 定な(+600Oeの外部磁界を加えても抵抗の低下が  
 僅か)磁化固着層に加えて、大きなスピバルブ膜面抵  
 抗 $R_s$ が得られ、面抵抗変化 $\Delta R_s$ も満足できるもので  
 あるので特に好ましい。ここで、再生出力はセンス電流  
 と抵抗変化の積に比例し、抵抗変化は抵抗変化率とスピ  
 ンバルブ膜の面抵抗の積に比例するので、抵抗変化率が  
 大きいだけでは面抵抗が小さい場合には高出力を得るこ  
 とができない。即ち、高出力を得るには、高い抵抗変化  
 率とともに、高い面抵抗が必要である。

【0257】図23は強磁性層Aの膜厚を3nm一定と  
 し、強磁性層Bの膜厚を変えた場合の磁界による抵抗変  
 化を示す図である。

【0258】図23にみられるように、強磁性層Aと強  
 磁性層Bの磁気膜厚とを等しくすると、+600Oeの  
 高磁界による抵抗の変化が小さく、従って媒体磁界、縦  
 バイアス層からの磁界や、記録部形成熱処理時の外部磁  
 界などに対して著しく安定な磁化固着層が実現できる。\*

表10

スピバルブ膜の構成:

Ta (5nm)/AuCu (2nm)/CoFe (5nm)/Cu (3nm)  
 /強磁性層A (CoFe)/Ru (0.9nm)/強磁性層B (CoFe)  
 /IrMn (10nm)/Ta (5nm)

強磁性層A 厚さ (nm)	強磁性層B 厚さ (nm)	抵抗変化率 $\Delta R/R$ (%)
3	3	7.3
3	2.5	7.8
3	2	7.7

例えば強磁性層A、強磁性層Bおよび磁化自由層にそれ  
 ぞれ、Co、CoFeおよびNiFeを用いて、非磁性  
 中間層にCuを用いた場合には、強磁性層Bと強磁性層  
 Aの磁気膜厚の比を0.7~0.9に設定して強磁性層  
 Bの厚みを2.5nmに設定した場合に、図24、図2  
 5および表11に示すような良好なESD特性を得るこ  
 とができる。ここに図24および図25はスピバルブ  
 素子にヒューマンボディモデルによる模擬のESD電圧

\*またESDによる磁化固着層の磁化反転の問題は、す  
 でに述べたようにドライブに組み込んだ固着磁化方向を補  
 償する回路による電流で、磁化方向を所望の方向に戻す  
 ことにより対応できる。

【0259】一方、強磁性層Aと強磁性層Bの磁気膜厚  
 を異ならせることによって、以下の利点を得られる。ま  
 ず第1に、スピバルブの基本的な構成である磁化自由  
 層と磁化固着層の磁化を直交させるための、熱処理によ  
 る磁化固着の操作が容易になる。第2に、強磁性層Bの  
 膜厚と抵抗変化率との関係を示す表10によって明らか  
 なように、強磁性層Bの磁気膜厚を強磁性層Aの磁気膜  
 厚よりも小さくすることによって、より高い抵抗変化率  
 が得られる。第3にESDによる磁化固着層の磁化反転  
 がほとんど起こらなくなり、ブレークダウン電圧近傍ま  
 で安定な再生出力が得られる。ここにブレークダウン電  
 圧はスピバルブ素子が電圧により破壊してスピバルブ  
 素子抵抗が増大し始める電圧である。

【0260】

【表5】

を与えた後の抵抗と出力を示し、図24は強磁性層Aと  
 強磁性層Bの磁気膜厚が等しい場合、図25は強磁性層  
 Aの磁気膜厚が強磁性層Bの磁気膜厚より大きい場合を  
 示す。また表11はスピバルブ素子に対するテストパ  
 ターンによるESD特性を示したものである。

【0261】

【表6】

表 11

スピナル膜構成:

Ta (5nm) / 磁化自由層 / Cu (3nm) / 強磁性層 A / Ru (0.9nm)  
 / 強磁性層 B / IrMn (10nm) / Ta (5nm)

素子構成: パターンニング無しの下シールド、下キャップ上に形成した CoPt / FeCo  
 下地ハード膜縦バイアスおよび電極が縦バイアス間隔よりも狭いリードオーバーレ  
 イドを用いた構造 (シールドは無し)。

電極間隔 = 1.3 μm

磁気膜厚比 ( $M_s \cdot t$ ) <sub>A</sub> / ( $M_s \cdot t$ ) <sub>B</sub>	強磁性層 A	強磁性層 B	磁化自由層	固着磁化 反転電圧	ブレーク ダウン電圧
0.75	CoFe(2nm)	CoFe(1.5nm)	CoFe(3nm)/NiFe(1.5nm)	反転せず	70V
0.8	CoFe(2.5nm)	CoFe(2nm)	CoFe(3nm)/NiFe(1.5nm)	反転せず	75V
0.83	CoFe(3nm)	CoFe(2.5nm)	CoFe(4nm)/NiFe(1.8nm)	反転せず	70V
0.85	Co(2nm)	Co(1.7nm)	Co(0.5nm)/NiFe(4nm)	反転せず	70V
0.71	CoFe(2.4nm)	CoFe(1.7nm)	CoFe(1nm)/NiFe(3nm)	65V	75V
0.88	CoFe(2.4nm)	CoFe(2.1nm)	CoFe(1nm)/NiFe(3nm)	65V	75V
1	CoFe(3nm)	CoFe(3nm)	CoFe(4nm)/NiFe(1.8nm)	50V	75V
0.667	CoFe(3nm)	CoFe(2nm)	CoFe(3nm)/NiFe(1.5nm)	55V	75V
0.93	CoFe(3nm)	CoFe(2.8nm)	CoFe(1nm)/NiFe(3nm)	55V	70V

これは ESD 発生時に、磁化固着層には電流磁界を主とする磁界が強磁性層 B に対し、強磁性層 A に対するよりも強く加わるが、その電流磁界の比、 $H(\text{current})_B / H(\text{current})_A$  が、磁気膜厚の逆比、 $(M_s \cdot t)_A / (M_s \cdot t)_B$  とほぼ一致するために、強磁性層 A と強磁性層 B の磁化と外部磁界とのエネルギーの変化量が相殺して、全体としてのエネルギー変化、

$$\{ (M_s \cdot t) \cdot H(\text{current}) \}_A - \{ (M_s \cdot t) H(\text{current}) \}_B$$

が小さい状態が実現でき、その結果 ESD 電流磁界では磁化固着層の磁化を動かすことができないためである。

【0262】図 23 に示すように、強磁性層 A が 3 nm、強磁性層 B が 2 nm であって、従って  $(M_s \cdot t)_B / (M_s \cdot t)_A = 0.67$  となる場合には、強磁性層 A、強磁性層 B とともに 3 nm の同図 (a) の場合に比べて、 $H_{uA}$  が低下し、従って磁化固着層の耐熱性も低下する。このように強磁性層 A よりも強磁性層 B の磁気膜厚を小さくした場合には、強磁性層 B に加わる反強磁性層からのバイアス磁界と同じ方向 (即ち、強磁性層 B の磁化と同じ方向) にセンス電流からの磁界が加わるように、センス電流の通電方向を選ぶことが好ましい。その理由は強磁性層 A の方が磁気膜厚が大きいと、従来の単層の磁化固着層のスピナル膜と同様に、強磁性層 A と強磁性層 B との磁気膜厚差に相当する漏洩磁界が磁化自由層に加わるので、磁化自由層と磁化固着層との磁化直交配置が乱され、再生出力の低下は再生波形の上下非

対称が増大するなどの問題を生じるが、この漏洩磁界は、スピナル膜における磁化と漏洩磁界を示す図 26 に示されるように、センス電流による磁界が交換バイアス磁界と同方向に加わるようにセンス電流を流すことによって相殺することができる。

【0263】非磁性中間層には Cu、Au、Ag 単体またはそれらを主成分とする合金を用いることが好ましい。その膜厚は抵抗変化率を得られる範囲である 1 ~ 10 nm 程度であれば基本的に使用できるが、特に本発明のスピナル膜では、1.5 nm ~ 2.5 nm の膜厚範囲が、磁化固着層と磁化自由層の間に発生する強磁性的結合磁界を 15 Oe 以下に抑制でき、且つ高い抵抗変化率が得られるので特に好ましい。

【0264】磁化自由層には、Co や CoFe、CoNi、CoFeNi などの Co 合金、NiFe 合金またはそれらの積層構成、例えば中間層側に 0.3 ~ 1.5 nm の薄い Co を介した NiFe 合金が用いられる。そして磁化自由層の膜厚は、1 ~ 10 nm が好ましい。

【0265】表 12 は磁化固着層 (磁化固着層) の厚みを 2.5 nm 一定とし、磁化自由層の厚みと抵抗変化率  $\Delta R/R$  との関係を示した表である。表 10 に示したように、本発明においては、磁化自由層厚は 2 ~ 5 nm が高い抵抗変化率を得るために特に好ましい。

【0266】

【表 7】

表 12

磁化自由層 厚さ (nm)	強磁性層 A = 強磁性層 B 厚さ (nm)	抵抗変化率 $\Delta R/R^*$ 磁化自由層が CoFe 単層 (%)	抵抗変化率 $\Delta R/R^{**}$ 磁化自由層が中間層後に 1 nm Co をはさんだ NiFe (%)
1	2.5	6.2	5.7
2	2.5	7.5	7.0
3	2.5	7.9	7.2
4	2.5	7.8	7.2
5	2.5	7.5	7.1
6	2.5	6.9	6.4
7	2.5	6.6	6.0

強磁性層 A と強磁性層 B は同じ厚さで CoFe 合金を用いた。

表 13 は磁化自由層の厚さを 4 nm 一定とし、磁化固着層の強磁性層 A の厚さと抵抗変化率  $\Delta R/R$  との関係を示した表である。表 11 に示すように、2 ~ 5 nm の磁化自由層の厚み  $t(F)$  と強磁性層 A の厚み  $t(P)$  との間に、

$$-0.33 \leq \{t(F) - t(P)\} / t(F) \leq 0. \quad *$$

表 13

磁化自由層厚さ $t(F)$ (nm)	強磁性層 A 厚さ $t(P)$ (nm)	抵抗変化率 $\Delta R/R$ (%)	$(t(F) - t(P)) / t(P)$
4.5	1	4.7	0.78
4.5	1.5	6.9	0.67
4.5	2	7.1	0.56
4.5	3	7.9	0.33
4.5	4	7.7	0.11
4.5	5	7.3	-0.11
4.5	6	6.8	-0.33
4.5	7	5.9	-0.66

磁化自由層は CoFe 合金

強磁性層 A と強磁性層 B は CoFe 合金

強磁性層 B の厚さは 3 nm

保護膜には Ta、Nb、Zr、Cr、Hf、Ti、Mo、W などの金属またはそれらの合金あるいはそれら金属の酸化物、窒化物などが用いられる。特に酸化物や窒化物では、例えば NiFe 酸化物、窒化アルミ、タンタル酸化物などの高抵抗の保護膜が、高い抵抗変化率を得るために好ましい。その膜厚は例えば 0.3 ~ 4 nm と極力薄いことが後述べる電極や縦バイアス層を形成する上で保護膜のエッチングによる除去が容易になるので好ましい。また、Ag、Au、Ru、Ir、Cu、Pt、Pd、Re などの貴金属単体または合金単層または積層体を、例えば CoFe 磁化自由層の場合には、Cu/Ru、Cu、Au、Cu 合金など、NiFe 磁化自由層の場合には Ag、Ru、Ru/Ag、Ru/Cu、Cu などを保護膜に用いてもよい。酸化物、窒化物、貴金属保護膜の上にさらに Ta などの高抵抗保護膜を形成してもよい。

【0268】磁化固着層と磁化自由層の磁化を直交させることは、次の方法によって実施できる。即ち、反強磁

\* 67.

の関係を有することが、高い抵抗変化率を得るために好ましい。

【0267】

【表 8】

性層 143 が IrMn、RhMn、RhRuMn などの  $\gamma$ -Mn 系の Mn リッチ合金の場合は、スピバルブの成膜を行う際に、磁気結合層 1442 までの成膜をスピバルブ素子の幅方向、即ちハイト方向に印加した磁界中で行った後に、反強磁性層 143 の交換結合バイアス磁界方向を一方に揃えるために熱処理を施す。なお、この反強磁性層 143 の交換結合バイアス磁界方向を一方に揃えるための熱処理は、強磁性層 B の成膜直後でもよいが、Ru などの磁気結合層がより酸化に強いいため、磁気結合層 1442 層まで成膜した方が好ましい。この熱処理は、成膜後リークをすることなく真空中で、Tb より高い温度にて短時間、好ましくは 10 分以下の短時間、完全に強磁性層 B が飽和する磁界中で行うことが好ましい。例えば Tb が 300℃ の IrMn では 350℃ で 1 分程度行う。

【0269】次にリークをすることなく、少なくとも磁気自由層成膜中にはスピバルブ素子のトラック幅方向に磁界を加えてその後のスピバルブ素子の成膜を行

う。反強磁性層 143 が PtMn や NiMn の規則合金の場合も同様であるが、 $\gamma$ -Mn 系の反強磁性層とは異なり、必ずしも強磁性層 B までの成膜を磁界中で行う必要はなく、その後の熱処理を 200℃ 以上の高温、好ましくは 270~350℃ で数時間、好ましくは 1~20 時間行う必要がある。熱処理後は同様に磁化自由層の成膜中に磁界を付与してその後のスピナル成膜を行う。

【0270】なお、いずれの反強磁性層も、スピナル成膜中での熱処理を、スピナル成膜後に行うこともできる。その場合には、磁気結合層 1442 の結合磁界を上回る磁界を加えて、強磁性層 A と強磁性層 B の磁化を完全に同方向（ハイト方向）に飽和させて熱処理することが好ましい。例えば、強磁性層 B / 磁気結合層 / 強磁性層 A が、CoFe2nm / Ru0.9nm / CoFe2nm の場合、Ru の結合磁界は約 6 kOe であることから、熱処理中に加える磁界は 7 kOe 以上が好ましい。この熱処理時に加える磁界を小さくするためには、スピナル膜を素子形状に加工する前に熱処理を行うことが好ましい。加工後では素子形状による反磁界のために、強磁性層 A と強磁性層 B を飽和させるのにより強い磁界が必要になる。

【0271】以上の方法により、磁化固着層 144 の磁化を所望の方向に固定させる。しかし、上記の熱処理が強い場合には、磁化自由層 146 や下シールド 11 の磁化容易軸が磁化固着層と同様にスピナル素子のハイト方向に向いてしまい、磁化固着層の磁化と直交させることが困難になる。磁化自由層や下シールドの磁化容易軸をトラック幅方向に向けるには、記録ヘッドにおけるレジストキュア工程において、シールドや磁化自由層がトラック幅方向に飽和する必要最小限度磁界、例えば 100~300 Oe 程度を加えて、シールドや磁化自由層の磁化容易軸をトラック幅方向に安定化することが好ましい。また、下シールドはスピナル成膜前にあらかじめ熱処理により、磁化容易軸をトラック幅方向に安定化しておくことが好ましい。

【0272】図 17 に示したアバットジクシオンタイプの素子構造、即ち、磁化自由層のトラック幅端部を除去してそこに縦バイアス層を形成した素子構造では、縦バイアス層に硬質磁性膜例えば Cr や FrCo などの下地のの上に形成した CoPt や CoPtCr など、あるいは強磁性層 151 と反強磁性層 152 を順次積層して強磁性層をハード化したものが用いられる。先に反強磁性層 152 を成膜して、次に強磁性層 151 を成膜してもよい。今後の狭トラックに対応して、トラック幅端での急峻な再生感度プロファイルを得るには、磁化自由層に対する縦バイアス強磁性層、即ち、硬質磁性層または反強磁性膜で交換結合バイアスされた強磁性層の磁気膜厚比、 $(Ms \cdot t)_{LB} / (Ms \cdot t)_F$  を 2 以下に設定することが好ましい。磁化自由層が 2~5 nm 厚、あるいは

は磁気膜厚で 3~6 nm 程度まで薄くなると、 $(Ms \cdot t)_{LB} / (Ms \cdot t)_F$  を 2 以下にするために、縦バイアス強磁性層も非常に薄くなり、例えば磁気膜厚で 12 nm 以下となる。

【0273】ところが一般に硬質磁性膜では 10 nm 厚程度に薄くなると高保磁力が得難くなる。例えば Ms が 1 T の CoPt 硬質磁性膜では、20 nm 厚では、2000 Oe の高保磁力であったものが、10 nm では 800 Oe に低下する。一方、強磁性膜 / 反強磁性膜タイプの縦バイアス層では強磁性膜 151 が薄くなるほど交換バイアス磁界が増大して固着が強固となる。例えば、Ms が 1 T の NiFe と 7 nm 厚の IrMn を積層した縦バイアス層では、20 nm 厚で 800 Oe であった保磁力が 10 nm 厚では 1600 Oe にまで増大する。この 1600 Oe は、従来の MR ヘッドで実績を有する値である。従って磁化自由層の厚さが極薄い領域、例えば 5 nm 厚以下となるような領域では、強磁性膜 / 反強磁性膜タイプの縦バイアス層を用いることが望ましい。

【0274】さらに、強磁性膜 151 / 反強磁性膜 152 の縦バイアス層では、強磁性膜 151 の飽和磁化は磁化自由層の飽和磁化とほぼ等しいか、それより大きいことが、なるべく小さな縦バイアス磁界でバルクハウゼンノイズを十分に除去する上で好ましい。即ち、強磁性膜 151 としては NiFe 合金でもよいが、より飽和磁化の大きい NiFeCo 合金、CoFe 合金、Co などがより好ましい。強磁性膜 151 として飽和磁化の小さい膜を用いて、その膜厚を大きくすることにより、漏洩磁界を強めてバルクハウゼンノイズの除去を行うと、特に狭いトラック幅になると再生出力の低下を引き起こす。

【0275】なお、図 17 ではスピナル膜全部を除去しないで、縦バイアス層を形成した場合を示したが、下地層 141 までエッチング除去してもよい。しかし強磁性層の結晶性を良好に保つためには、縦バイアス層を形成する前のエッチングする深さとして、少なくとも下地層 142 を残してその結晶性改善効果を利用することが好ましい。膜厚制御の観点からは、より厚い反強磁性層 143 を若干エッチングして、その交換バイアスを弱めて良好なハード膜特性の縦バイアス層を得ることが好ましい。非磁性中間層の途中までエッチングを終了してその上に強磁性膜 151 / 反強磁性膜 152 からなる縦バイアス層を付与してもよい。なお、結晶性改善のために、あるいは磁化固着層や反強磁性層 143 と縦バイアス層との磁気結合を弱めるために、強磁性膜 151 の下に、下地層 143 と同様にごく薄い下地層 153 を設けてもよい。磁化自由層と縦バイアス層との磁気結合の低減を最小限に止めるために、下地層 153 の厚みは 10 nm 以下が好ましい。

【0276】硬質磁性膜を用いる場合にも、同様に磁化自由層と硬質磁性膜の飽和磁化を揃えることが好ましい。しかし、CoFe などの高い飽和磁化自由層に匹敵

する高い飽和磁化の硬質磁性膜を作製することは通常困難である。そこで硬質磁性膜の下地としてFeCoのような高い飽和磁化の膜を用いて、磁化自由層との飽和磁化とのバランスを保つ方法が、小さな縦バイアス磁界でハルクハウゼンノイズを除去するのに適する。

【0277】反強磁性膜152には、スピバルブ膜に用いたものと同様な反強磁性体を用いることができる。しかし、スピバルブの反強磁性層の交換バイアス磁界はハイト方向、そして縦バイアス層の反強磁性膜152の交換バイアス磁界はトラック幅方向と、互いに直交させる必要がある。そこで、例えば両者のブロッキング温度Tbを異ならせて、最初に高いTbを有する反強磁性層の交換バイアス磁界方向を熱処理により規定した後、それより低いTbを有する反強磁性膜に対してより低温の熱処理を行って、高Tb反強磁性層の交換バイアス方向を安定に保ったまま、低いTbを有する反強磁性膜の交換バイアス磁界方向を設定することにより、互いの交換バイアス磁界を直交させることができる。

【0278】具体的には、反強磁性膜152には、PtMnやPdPtMnなどの熱処理により、H<sub>UA</sub>を発現する反強磁性膜でもよいが、磁化固着層が安定な温度で熱処理できるTbが200～300℃の、RhMn、IrMn、RhRuMn、FeMnなどを、スピバルブ膜の反強磁性層にはそれよりTbが高い反強磁性体、即ち、IrMn、PtMn、PtPdMnなどを用いると、前述したレジストキュア熱処理工程にてスピバルブ膜の磁化固着層磁化の方向を乱すことなく、反強磁性膜152の交換バイアス方向をトラック幅方向に規定できる。即ち、本発明の特徴であるブロッキング温度以下でピン磁化が急激に安定化する性質を利用することによって、両反強磁性膜の間のブロッキング温度差がわずか数十℃であっても、縦バイアスと磁化固着層磁化とを良好に直交させることができる。また反強磁性膜152に磁界中成膜で交換バイアス磁界を付与できるIrMn、FeMn、RhMn、RhRuMn、CrMnPt、CrMnなどを用いると、熱処理が不要なために、スピバルブ膜の反強磁性層143のバイアス磁界方向が乱されることはなく、スピバルブ膜の反強磁性層143にどのような反強磁性層を用いても、縦バイアス方向と磁化固着層磁化方向とを直交させることができる。

【0279】一方、図27に示すように、磁化自由層のトラック幅端部の保護膜147のみをエッチング除去して、その上に反強磁性膜を交換結合積層した構造でも、磁化自由層に縦バイアスを加えることができる。縦バイアス層15は反強磁性層152とその下地として磁化自由層との交換結合を強めるためのバッファ層1511を介することが好ましい。このバッファ層1511はFe、Co、Niなどからなる強磁性層であることが好ましい。縦バイアスの磁化方向の規定は強磁性層1511／反強磁性層152の縦バイアスの場合と同様である。反

強磁性層を用いた縦バイアス方式は、硬質磁性膜方式のように余分な縦バイアス磁界を発生させてヘッドの感度低下を引き起こしたりすることなく、バルクハウゼンノイズを抑制できる利点がある。

【0280】（実施の形態3）図28に本発明の第3実施形態を示す。図28は図21とはスピバルブ膜の構造が異なる。図27において、下ギャップ12の上に形成されたスピバルブ膜14は、Ta、Nb、Zr、Hfなどの厚さ1～10nmの非磁性下地層141、必要に応じて厚み0.5～5nmの第2の下地層142、磁化自由層146、厚さ0.5～4nmの中間層145、磁化固着層144、反強磁性層143、必要に応じて厚さ0.5～10nmの保護膜147から構成される。ここで磁化自由層（フリー層）146、中間層145、磁化固着層144、反強磁性層143は実施形態2と同じ構成である。

【0281】下地層142には、Au、Cu、Ru、Cr、Ni、Ag、Pt、またはRh、またはそれらを主成分とする合金を用いると、特に磁化自由層にCoFe合金を用いた場合に抵抗変化率の耐熱性を高めることができる。

【0282】図27において、図21と同じ一対の縦バイアス層15、一対の電極16によりスピバルブ14と合わせてスピバルブ素子13が構成される。さらにその上に図21と同様、上ギャップ層17、上シールド18が構成される。

【0283】（実施の形態4）図29は本発明のさらに他の実施形態であって、本発明をデュアルタイプのスピバルブ構造に適用した場合の例を示すものである。

【0284】図29においては実施形態2の図21および実施形態3の図27の場合と同様に、下シールド11、下ギャップ12の上に、一対の縦バイアス層15、一対の電極16、縦バイアス層15、スピバルブ膜14からなるスピバルブ素子13が形成され、その上に上ギャップ17、上シールド18が形成される。しかし、電極16の間隔やスピバルブ膜14の構成が図21および図27とは異なる。

【0285】スピバルブ膜14は、Ta、Nb、Zr、Hfなどの厚さ1～10nmの非磁性下地層141、必要に応じて厚さ0.5～5nmの第2の下地層142、反強磁性層143、磁化固着層144、厚さ0.5～4nmの中間層145、磁化自由層146、厚さ0.5～4nmの第2の中間層148、第2の磁化固着層149、第2の反強磁性層150、必要に応じて厚さ0.5～10nmの保護膜147から構成される。

【0286】磁化固着層144と磁化固着層149の少なくとも一方に、図17と同じ強磁性層A、磁気結合層、強磁性層Bからなる積層磁化固着層を用いる。そして1)磁化固着層149にはSyAF磁化固着層、磁化固着層144には従来の単層磁化固着層の組み合わせ、

2) 逆に磁化固着層 144 には S y A F 磁化固着層、磁化固着層 149 には従来の単層磁化固着層の組み合わせ、あるいは 3) 磁化固着層 149 と磁化固着層 144 の双方とも S y A F 磁化固着層の組み合わせを用いることができる。

【0287】縦バイアス層 15 はいわゆるアバットジャンクションタイプの素子構造であるが、図 17、図 27、図 28 と同様な縦バイアス層 15 をリフトオフ法、即ち、フォトレジストをマスクにして、スピバルブ膜のトラック幅端部をエッチング除去した後、スパッタ、蒸着、イオンビーム成膜などの方法により、縦バイアス層 15 を形成するのに際して、スピバルブ膜 14 のエッチング除去を少なくともスピバルブ膜 14 の導電体層部をのこすように行うことが好ましい。例えば反強磁性層 143 が I r M n のような  $\gamma$ -M n 系合金の場合には、反強磁性層 143 の一部を少なくとも残すことが好ましい。

【0288】トラック幅端部に導電体部を残すと、アバットジャンクションの接触抵抗が下がるので、低抵抗のスピバルブ素子 13 が実現しやすく、このため静電気に対して強いヘッドが実現できる。勿論、トラック幅端部のスピバルブ膜のすべてをエッチング除去して縦バイアス層を形成してもよい。

【0289】電極 16 は縦バイアス層と一括してリフトオフ形成してもよいが、この場合は電極間隔と縦バイアス層の間隔がほぼ一致する。あるいは電極形成を縦バイアス層形成とは分離して、電極間隔を縦バイアス層の間隔より狭めて形成した、いわゆるリードオーバーレイド構造としてもよい。リードオーバーレイド構造とすると、特に縦バイアス層に硬質磁性層を用いた場合には、硬質磁性層からの漏洩磁界の影響を電極とスピバルブ膜が積層されているトラック幅エッジ部近傍に閉じ込めることができ、電極間で規定される再生トラック幅の、トラック幅方向の感度プロファイルシャープに高精度で規定できるメリットがある。特に再生トラック幅がサブミクロンとなるような高密度記録では、そのメリットが従来の方法に比べてより明確になる。このリードオーバーレイド構造は当然図 21 や図 27 の実施形態にも適用できる。

【0290】(実施の形態 5) 図 30 は本発明のさらに他の実施形態である。図 21 に示した実施の形態 2 と同様に、基板 (図示せず) 上に下シールドおよび下キャップ (図示せず) を形成し、さらにその上にスピバルブ膜 13 を形成し、さらにその上に図示していないが上キャップ、上シールド、記録部を形成する。スピバルブ膜 13 のトラック幅両端には一対の縦バイアス層 15 および電極 16 を形成する。縦バイアス層には一例として、下地層 153、強磁性膜 151、反強磁性膜 152 からなる積層体を用いる場合を示した。縦バイアス層には当然 C o P t などの硬質磁性膜を用いることができ

る。

【0291】電極 16 は T a / A u / T a などの低抵抗金属を少なくとも含む材料を用いて形成し、電極間隔 L D は縦バイアス層間隔 H M D よりも狭く形成され、スピバルブ膜 13 と電極 16 はトラック幅両端近傍で面接触する領域を有する。縦バイアス層や電極は通常リフトオフにより形成されるが、イオンミリング法や反応性イオンエッチング法などにより形成してもよい。プロセス工程が煩雑になるが、特に高精度の電極形成にはドライプロセスが適する。

【0292】縦バイアス層 15 が存在しない電極 16 直下のスピバルブ膜 13 領域では、電極の抵抗値がスピバルブ膜の抵抗値に比べて十分に小さい場合、例えば 1 / 10 以下の場合には、さらにスピバルブ膜の磁化自由層 146 の磁化が媒体磁界がほぼゼロのとき、トラック幅方向にほぼ規定されていると、スピバルブ膜の電極直下などの電極間以外の箇所では再生感度が大幅に低減されるので、電極間隔 L D で再生トラック幅が規定でき、トラック幅端における急峻な再生感度分布が実現できる。

【0293】さらにスピバルブ膜 13 と電極 16 は面接触領域が通常のアバットジャンクション方式と比べて十分広くとれるので、電極とスピバルブとの接触抵抗が十分に小さく制御でき、その結果低抵抗のスピバルブ素子が実現でき、低ノイズでしかも E S D に強い磁気抵抗効果ヘッドが実現できる。

【0294】ここで今後記録密度を高めるために再生トラック幅を狭めてゆくには、電極間隔 L D を狭めてゆく必要がある。一方、電極間隔が著しく狭くなると素子の幅、即ちハイトをそれ以上に狭めることは困難になる。従って H D を L D よりも大きくすることが、ヘッドを歩留まりよく製造する上で好ましい。具体的には、ヘッド量産時の歩留まりを良好に保つために機械加工で寸法を決定するハイトについては 0.5  $\mu$  m 程度かそれ以上が必要であり、再生トラック幅が 0.5  $\mu$  m 以下に狭まる場合には H D を L D よりも大きく設定することが好ましい。しかしその場合には以下の問題が発生する。

【0295】その第 1 の問題は、再生を行うスピバルブ膜領域の抵抗が減少するために、再生出力が減少することである。この問題に対してはスピバルブ膜の面抵抗を高めることによって回避された。通常の S y A F 固着層では固着層厚が従来単層の磁化固着層よりも厚いので高い面抵抗を得るのが困難であったが、表 14 および表 15 に示すように、本発明では磁化固着層の厚み、非磁性中間層および磁化自由層の厚みの合計を 14 n m 厚以下に抑えることにより、16  $\Omega$  以上の高い面抵抗と 8 % 以上の高い抵抗変化が両立できる。

【0296】

【表 9】

表14

スピバルブ膜構成: Ta (5nm)/Au (2nm) IrMn (7nm)/強磁性層B/ 磁化結合層/ 強磁性層A/ 中間非磁性層/ 磁化自由層/ Ta

強磁性層B 厚さ (nm)	磁化結合層 厚さ (nm)	強磁性層A 厚さ (nm)	非磁性中間 層厚さ (nm)	磁化自由層 厚さ (nm)	強磁性層B～磁化自 由層合計厚さ (nm)	R <sub>s</sub> (Ω)	ΔR/R (%)
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2nm)	CoFe (0.5nm)/NiFe (2.5nm)	9.9	23.5	8.3
CoFe (1.5nm)	Ru (0.8nm)	CoFe (2nm)	Cu (2nm)	CoFe (0.5nm)/NiFe (4nm)	10.8	19.5	8.7
CoFe (1.5nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (3nm)	9.9	19.5	9.7
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2nm)	Co (1nm)/NiFe (5nm)	12.9	18.2	8.9
CoFe (1.5nm)	Ru (0.9nm)	CoFe (1.5nm)	Cu (2nm)	Co (1nm)/NiFe (3nm)	9.9	22.8	8.1
CoFe (2nm)	Ru (0.9nm)	CoFe (2.5nm)	Cu (2nm)	CoFe (3nm)	10.4	19.4	10.7
CoFe (2nm)	Ru (1nm)	CoFe (2.5nm)	Cu (2.5nm)	Co (1nm)/NiFe (4nm)	13	18	8.1
CoFe (2.2nm)	Ru (0.8nm)	CoFe (2.5nm)	Cu (2nm)	CoFe (2nm)/NiFe (4.5nm)	14	16	8.7
CoFe (3nm)	Ru (0.9nm)	CoFe (3nm)	Cu (3nm)	CoFe (1nm)/NiFe (7nm)	17.8	13	6.5
CoFe (3nm)	Ru (0.9nm)	CoFe (3nm)	Cu (3nm)	CoFe (3nm)/NiFe (2nm)	14.8	12	7.2
CoFe (2.5nm)	Ru (0.8nm)	CoFe (3nm)	Cu (2.5nm)	CoFe (1nm)/NiFe (7nm)	16.8	14.7	7.3
CoFe (3nm)	Ru (0.7nm)	CoFe (3nm)	Cu (3nm)	CoFe (5nm)	14.7	12.5	8.2

【0297】

\* 20 \* 【表10】

表15

スピバルブ膜構成: Ta (5nm)/NiFe (2nm) PtMn (7.5nm)/強磁性層B/ 磁化結合層/ 強磁性層A/ 中間非磁性層/ 磁化自由層/ Ta

強磁性層B 厚さ (nm)	磁化結合層 厚さ (nm)	強磁性層A 厚さ (nm)	非磁性中間層 厚さ (nm)	磁化自由層 厚さ (nm)	強磁性層B～磁化自 由層合計厚さ (nm)	R <sub>s</sub> (Ω)	ΔR/R (%)
Co (2nm)	Ru (0.9nm)	Co (2nm)	Cu (2.5nm)	Co (1nm)/NiFe (2nm)	10.4	23.5	18.5
Co (2nm)	Ru (0.9nm)	Co (2nm)	Cu (2.5nm)	Co (0.5nm)/NiFe (2nm)	9.9	19.7	7.9
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (1nm)/NiFe (2nm)	9.7	18.6	8.7
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (3nm)	10.4	18.3	9.1

【0298】このような極薄のスピバルブ膜を用いて高抵抗変化率を実現するためには、1) 磁化固着層の強磁性層Aと強磁性層Bにはfcc相が安定なCoFe、CoNi、CoFeNi合金を用いること、2) 磁化自由層にも少なくとも中間非磁性層との界面近傍にはCo、CoFe、CoNi、CoFeNi合金を用いること、3) 反強磁性膜にはPtMn、PtPdMn、IrMn、RhMn、RhRuMnなどの貴金属元素を含む反強磁性層を用いることが好ましい。

【0299】HDをLDよりも大きく設定する場合の第2の問題は、バルクハウゼンノイズの発生である。従来の電極間隔と縦バイアス膜の間隔HMDがほぼ一致するアバットジャンクション方式のスピバルブ素子では、HMDがHDよりも小さくなり、磁化自由層の形状はHD方向が長い長方形形状になってしまい、反磁界が弱いハイト方向に磁化自由層の磁化が向きやすくなり、その結果バルクハウゼンノイズが発生する。これに対し、本発明ではスピバルブ膜の形状がHMDがHDよりも大きくトラック幅方向に長いので、磁化自由層の磁化がハ

イト方向に向きやすくなるということがなく、このためバルクハウゼンノイズの除去は容易であり、この点に関し歩留まりよくヘッド製造ができる。

【0300】具体例として、1) HD=0.5μm、LD=0.45μm、HMD=1.3μm、2) HD=0.4μm、LD=0.35μm、HMD=0.8μmなどで本発明の効果が十分に発揮される。

【0301】なお、図29には磁化自由層と基板の間に磁化固着層が配置された場合を示したが、磁化自由層が基板と磁化固着層との間に存在する場合についても同様に適用できる。

【0302】(実施の形態6) 図31に本発明のさらに他の実施の形態を示す。図示していない基板、下シールド、下ギャップを形成され、その上に一対の縦バイアス層15がリフトオフ法や、イオンミリングや反応性イオンエッチングなどのドライプロセスにより、形成される。図29においては縦バイアス層の一例として、実施の形態2で示したと同様の反強磁性層に適した下地層153、IrMn、RhMn、CrMnなどの反強磁性膜

152、CoFe、NiFe、Coなどの強磁性膜151の積層体からなる場合を示したが、実施の形態2で示した他の各縦バイアス層が適用できる。

【0303】この上にスピバルブ膜13が形成される。スピバルブ膜13は、縦バイアス層からのバイアス磁界を有効に磁化自由層143に付与するために、磁化固着層より基板側に磁化自由層143を配置して縦バイアス層15と磁化自由層143とが接近し易くすることがより好ましい。磁化自由層143の下地層141、142の厚みは縦バイアス層からのバイアス磁界を有効に磁化自由層に付与するために、10nmであることが好ましい。またスピバルブ膜13と縦バイアス15との面接触領域は極力小さくすることがバルクハウゼンノイズを抑制する上で好ましい。

【0304】スピバルブ13の上には一対の電極16がリフトオフ法やイオンミリング法、反応性イオンエッチング法により形成される。図示していないが、さらにその上に上ギャップ、上シールド、記録部が形成される。

【0305】また実施の形態5にて示したと同様に、H20 DはLDより大きく、且つHMDより小さくすることにより、挟トラック幅に適した再生ヘッドがなく歩留まりよく製造できる。また、磁化固着層、非磁性中間層、磁化自由層の合計厚みを14nm以下とすることで、スピバルブ膜13の抵抗値を高めて再生出力を高め、高感度な磁気抵抗効果ヘッドを得ることができる。

【0306】だ実6。

(第7の実施の形態：耐熱性及び鏡面反射効果と低磁歪の実現)次に、「耐熱性及び鏡面反射効果と低磁歪の実現」という観点から、本発明の第7の実施の形態について説明する。

【0307】まず、本実施形態の具体例を紹介する前に、本発明者が本実施形態に至る過程で認識した課題について説明する。

【0308】高性能のスピバルブ膜(以下、SV膜と記す)を実用化するにあたって、本発明者が認識した課題は、以下に大別することができる。

【0309】(1)耐熱性が悪い(特に初期プロセスアニールに対して)。

【0310】(2)再生感度のより一層の向上を図る上でMR変化率が不足している。

【0311】(3)比較的大きなMR変化率が得られるCoFe合金層単層で感磁層を構成した場合に磁歪制御ができず、良好な軟磁気特性が得られない。

【0312】これらのSV膜の課題について以下に詳述する。

【0313】(1)耐熱性

SV膜の感磁層の一般的な構成としては、NiFe(数nm)/Co(1nm程度)やNiFe(数nm)/CoFe(1nm程度)が知られている。このような感磁

層を用いたSV膜構造としては、

(a) Ta(5nm)/NiFe(10nm)/Co(1nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

(b) Ta(5nm)/Cu(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

などが挙げられる。

【0314】上記したようなSV膜では、250℃×4H程度のプロセスアニールでas-depo時のMR値に対して相対比で約20%以上ものMR劣化が生じてしまう。例えば(a)のSV膜ではas-depo時のMR変化率6.4%が250℃×3Hのアニール後には4.7%とas-depo時に対して相対比で20%以上も劣化してしまう。このアニール工程はヘッド作製上欠かすことのできない工程である。た、NiFeを感磁層として用いていない(b)のSV膜でも、as-depo時のMR変化率は8.1%であるのに対して、250℃×3Hのアニール後には6.5%とas-depo時と比較して約20%の劣化が生じる。このようなMR変化率の劣化を磁気特性を犠牲にすることなく改善する手法、すなわち耐熱性の改善策は今のところ見出されていない。

【0315】高密度化に向けた磁気ヘッドでは、より高いMR変化率を有するSV膜が望まれているが、上述したように現在までに得られているSV膜では、as-depo時に得られているMR変化率を、ヘッドの作製工程上不可欠な熱プロセスにおいて著しく低下させている。これは10Gdpsi以上というような記録密度に対応させたMRヘッドを開発する上で、是非とも解決しなければならない問題である。

【0316】(2)反射効果の利用によるMR変化率の向上

高MR変化率を達成するためには、(1)で示したas-depo時に得られていたMR変化率を熱プロセス後にいかにして保つかということと共に、MR変化率の絶対値をいかにして上げるか、もしくはas-depo時ではフルポテンシャルのMR変化率が得られていなくても、熱プロセス後に良好なMR変化率が得られるような膜をいかにして実現するかということも重要である。

【0317】GMR効果は、電子の平均自由行程よりも短い範囲では磁性層/非磁性層の積層膜の層数が多いほどスピン依存散乱をうける回数が増えるので、MR変化率が大きくなる。しかしながら、SV膜構造のように、実際にヘッドで用いられるGMR膜の構造においては、磁化固着層/非磁性中間層/感磁層といったユニットしかないため、一般的には平均自由行程よりも短い膜厚になっており、MR変化率的に損をしている。

【0318】これを少しでも改善するために層数を増やした構造として、磁化固着層を上下2層とし、その間に

感磁層を配置したデュアルスピンバルブ膜（またはシメトリースピンバルブ膜（以下、D-SV膜と記す））が知られている。これも1つの対策ではあるが、現段階では実用上の問題を全て解決するまでには至っていない。例えば、感磁層にとっての下地が非磁性中間層となるD-SV膜では、感磁層の軟磁気特性、例えば反磁界 $H_K$ や磁歪入などを全て満足させることは難しい。さらに、上下2つの磁化固着層を用いた場合、これら2層の磁化を固着する2層の反強磁性膜のプロッキング温度が等しいほうが望ましいが、実際には下側に位置している反強磁性膜と非磁性中間層や感磁層を介して上層側に位置する反強磁性膜の特性を等しくすることは難しい。よって、MR変化率の点からはD-SV膜は好ましい構成であるが、実用性という観点からは多くの課題を含んでいる。

【0319】そこで、現在実用化されている反強磁性膜が1層の一般的な構造のSV膜の特性を向上させる1つの手段として、鏡面反射効果が検討されている。これは磁性層／非磁性中間層／磁性層のGMR膜の基本ユニットの片側もしくは上下両側に反射膜を配して電子を弾性的に反射させ、GMR膜の基本ユニット内での平均自由行程を長くするものである。

【0320】従来はGMR膜の基本ユニットの上下層では非弾性的な散乱を受けていたため、本来もっているはずの平均自由行程の距離だけ電子が移動できず、GMR膜の基本ユニットの膜厚以上のスピン依存散乱を受けることができないため、MR変化率的に損をしていた。それが理想的な上下両層の反射膜を用いれば、見かけ上GMR基本ユニットが無限大の人工格子と等価になり、本来移動できるはずの平均自由行程の分だけスピン依存散乱を受けることができるようになるため、MR変化率が向上する。このように、非磁性中間層の上下に位置する磁性層の外側にある反射膜自体は、スピンに依存した反射膜でなくとも、スピンに依存しない反射で十分効果を発揮する。

【0321】上記した効果は一般的なSV膜構造に限らず、D-SV膜においても効果を発揮する。ただし、層数が元々多く、本来の平均自由行程分だけスピン依存散乱を受けている無限層数の人工格子においては、反射膜の効果はない。このように、元々の層数が少ないSV膜構造ほど効果が大きい。

【0322】従来、上述したような鏡面反射効果を積極的に利用したSV膜としては、以下に示すようないくつかの構造が提案されている。

【0323】(c) Si基板／NiO(50nm)／Co(2.5nm)／Cu(1.8nm)／Co(4nm)／Cu(1.8nm)／Co(2.5nm)／NiO(50nm)

(d) Si基板／NiO(50nm)／Co(2.5nm)／Cu(2nm)／Co(3nm)／Au(0.50

4nm)

(Ref. J. R. Jody et. al., IEEE Mag. 33 No. 5. 3580(1997))

(e) MgO基板／Pt(10nm)／Cu(5nm)／NiFe(5nm)／Cu(2.8nm)／Co(5nm)／Cu(1.2nm)／Ag(3nm)

(Ref. 川分康博他、日本金属学会 1997年春季大会講演概要p142)

(f) Si基板／Si<sub>3</sub>N<sub>4</sub>(200nm)／Bi<sub>2</sub>O<sub>3</sub>(20nm)／Au(4nm)／NiFe(4nm)／Cu(3.5nm)／CoFe(4nm)

(Ref. D. Wang et al., IEEE Mag 32 No. 5. 4278(1996))

なお、上述したSV膜構造のうち、下線を付した部分が鏡面反射膜と考えられている部分である。

【0324】上記(c)のSV膜では、上下両層とも酸化物からなる鏡面反射膜を用いている。単純に考えても、電子の波の反射を起こすためには、金属よりもポテンシャルバリアの高い絶縁性の酸化物を用いたほうが、鏡面反射効果が大きく有効であると考えられる。さらに、NiO膜は酸化物反射膜であると同時に、反強磁性膜でもあるため、NiOに接している磁性層の磁化を固着する役割も果たしている。上記構成はD-SV膜であるが、ノーマルSV膜、反転SV膜などの反強磁性膜が1層の構造でも片側の鏡面反射は得られると考えられる。しかしながら、このような膜ではいくつかの不具合があり、現段階では実用的ではない。

【0325】まず、NiOは交換結合力が弱く実用性が低い。弱い結合磁界では記録媒体からの漏洩磁界によって磁化固着層の磁化方向が不安定となり、出力が変動するおそれがある。さらに、上層に酸化物層を用いる場合には、NiOにしろ、またキャップ層として別の酸化物を用いるにしろ、リード電極との接触抵抗が大きくなってしまふ。接触抵抗の増大はESD(electro static discharge: 静電破壊)を引き起こしやすくなるために望ましくない。さらに、CoFeを感磁層に用いた場合、CoFeはfcc(111)配向させなければ良好な軟磁性を実現できないことが分かっている。感磁層が下層に位置する場合に、感磁層の下地として酸化物層を用いることはCoFeにとってfcc(111)配向のバッファ層を失うことになるため、軟磁気特性との両立が困難となる。

【0326】また、(d)のSV膜では下地層にNiOの反射膜兼反強磁性膜を用い、さらに膜表面のAu層が反射膜となっている。また、(e)のSV膜でも同様に、膜表面のAg膜が反射膜となっており、Ag膜と膜表面とのポテンシャル差を利用して鏡面反射効果を引き出している。膜表面での反射膜として、AuやAgのような貴金属膜で効果が得られた理由は明らかではないが、1つの理由として(d)の文献には、膜表面での表面拡散が遷移金属より貴金属の方が起こりやすいため、貴金属膜表面では平坦性が高くなり、反射効果を引

き出しやすくなっているためであると記載されている。

【0327】上記したような金属膜を膜表面に用いた反射膜では、酸化物反射膜のときの問題点であったリード電極との接触抵抗が小さくできる点では有利である。しかしながら、AuやAgのような貴金属膜の膜表面での鏡面反射効果を利用した場合、実際の素子では効果が失われる可能性が高い。つまり、実際のMR素子やMRヘッドではSV膜の表面がそのまま晒されていることはまれであり、何らかの膜がSV膜上に積層されることが普通である。

【0328】例えば、シールド型MRヘッドにおいては、アルミナなどからなる上部磁気ギャップ膜がSV膜上に積層される。(d)の文献に記載されているように、鏡面反射効果は表面や界面での状態が反射効果に大きく影響する。それが元々膜表面での反射効果を利用して膜の上に別の膜が積層されると、反射効果は当然変ってしまう。このように、SV膜上に積層される膜によりMR特性が変動する膜構造は、実用面で問題がある。

【0329】実際に、(d)のSV膜のAu膜表面に、通常保護膜としてよく用いられるTa膜を積層すると、反射効果が失われると報告されている。このように、膜表面での鏡面反射効果を利用したSV膜は、実際のデバイス構造を想定した場合には効果が変動してしまうため、実用的なSV膜とは言えない。

【0330】(f)のSV膜は(d)と同様にAu膜を鏡面反射膜として用いているが、これは膜表面での反射効果ではなく、金属膜同士の膜界面での鏡面反射効果を引き出したものである。ここで、Au膜は適当な下地層がない基板上に直接成膜するとアイランド成長しやすいことが知られており、これを抑制するために(f)のSV膜では下地に工夫を凝らして、Au膜表面をできるだけフラットにし、その上に積層されるNiFeとの界面をシャープにしている。

【0331】しかしながら、(f)の下地層は実用的な手法とは言えない。すなわち、Au膜をBi<sub>2</sub>O<sub>3</sub>膜上に成膜し、350℃でアニールを行うと良好な反射効果が引き出せることを利用して、厚さ20nmのBi<sub>2</sub>O<sub>3</sub>膜を下地として用いている(Ref. C. R. Tellier and A. J. Tosser, Size Effects in Thin Films, Chapter I. Elsevier, 1982, L. I. Maissel et al., Handbook of Thin Film Technology, McGRAW-Hill Publishing Company, 1983)。

【0332】さらに、Si<sub>2</sub>O<sub>3</sub>膜の下地として厚さ200nmのSi<sub>3</sub>N<sub>4</sub>膜を用いている。つまり、合計220nmもの厚さの下地膜をAu膜の下地として用いた上に、350℃という高温でのアニール工程を経ている。220nmという膜厚は今後高密度化に伴ってますます狭ギャップになることを考えれば著しく不利となるだけでなく、実用性は極めて低いものである。さらに、

350℃という高温での熱処理は、GMR膜にとって基本となるスピン依存散乱を起こす磁性層/非磁性中間層界面で界面拡散を招き、MR変化率が著しく劣化してしまう。この温度はたとえ耐熱性に優れたCo(CoFe)/Cu/Co(CoFe)積層膜を用いたSV膜でも界面拡散が生じてしまう温度である。

【0333】(3)CoFeの磁歪制御  
CoFe層を感磁層として用いる場合、fcc(111)配向した下地層を適用することでCoFe層をfcc(111)配向させ、これにより軟磁気特性を向上させることが可能であることが見出されている。ここでは、fcc(111)配向した下地層としてCu層やAu層が用いられている。しかしながら、軟磁気特性のうち1つの重要な要素である磁歪については全く制御されておらず、かつ耐熱性も下地層に大きく依存することを今回見出した。例えば、上記公報に基づくSV膜としては以下に示すような膜構造が挙げられる。

【0334】(g) Ta(5nm)/Cu(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

(h) Ta(5nm)/Au(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

上記した(g)の膜では、Cu膜はfcc(111)配向しており、このfcc(111)Cu膜上のCoFe層もfcc(111)配向して軟磁性は実現できるものの、(i)耐熱性が悪い(as-depo: 8.1%→250℃×4H後: 6.5%(MR変化率は相対比で20%劣化))、(ii)磁歪λは $-1.4 \times 10^{-7}$ と絶対値が大きいなど、必ずしも実用性を十分に満足しているとは言えない。磁歪λの明確な指針はないが、1つの基準としては $-1.0 \times 10^{-7} \sim +1.0 \times 10^{-7}$ 程度が望ましいといえる。

【0335】さらに、fcc材料としてCuに代えてAuを用いた場合(h)の膜)にも、(i)耐熱性が悪い(as-depo: 8.4%→250℃×4H後: 6.5%(MR変化率は相対比で23%劣化))、(ii)磁歪λは $+3.3 \times 10^{-7}$ と絶対値が大きいなど、Cu膜を用いた場合と同様に、必ずしも実用性を十分に満足しているとは言えない。

【0336】上記(g)、(h)のスピンバルブ膜のXRDパターンを $\theta-2\theta$ スキャンで測定して評価した。CoFe/Cu/CoFe3層ではほぼ同様なdスペーシング値となっているため、1つのピークになっていたの、そのピーク値をとった。このとき、Cu上のCoFe/Cu/CoFe3層のfcc配向のd-(111)スペーシング値は2.054nmであり、Au上のCoFe/Cu/CoFe3層のfcc配向のd-(111)スペーシング値は2.086nmであった。後述するように、これらCu上およびAu上のd-(111)

スペーシング値の中間値にすれば、小さな適切な磁歪値をとることができることから、Cu上の小さすぎるd-(111)スペーシング値、Au上の大きすぎるd-(111)スペーシング値は好ましくないことが分かった。

【0337】このように、CoFe層からなる感磁層を用いる場合、単にfcc(111)配向させた下地層上に成膜しても、磁歪の点から不十分であることが分かった。なお、磁歪を満足させる手法の1つとして、零磁歪近傍でかつfcc(111)配向させたNi<sub>80</sub>Fe<sub>20</sub>上にCoFeを成膜し、磁歪的にほぼ零のNiFeにより感磁層全体として磁歪を零にする構造(上記した(a)の構成)が挙げられるが、前述したようにこの構成はMR特性の熱プロセス劣化が大きいという問題を有している。

【0338】上述したように、従来のスピバルブ膜は熱プロセスによるMR変化率の低下が大きいことから、スピバルブ膜の耐熱性を向上させることが望まれている。

【0339】また、スピバルブ膜のMR変化率の向上策として鏡面反射効果が注目されているが、従来のスピバルブ膜における反射膜は酸化物などの絶縁物であったり、また膜表面での反射効果を利用したものであるため、例えばリード電極との接触抵抗の増大によりESDを引き起こしたり、あるいはスピバルブ膜上に保護膜などを形成すると鏡面反射効果が失われるなど、実用性に劣るなどの問題を有している。さらに、界面で反射効果を利用することも検討されているが、そのために多大な下地層を設ける必要があるなど、実用性は極めて低いものであった。このようなことから、素子や磁気ヘッドとしての実用性を考慮した上で、鏡面反射効果によりスピバルブ膜のMR変化率を向上させることが望まれている。

【0340】さらに、スピバルブ膜の軟磁気特性を高める上で、CoFe合金などからなるCo系磁性層の磁歪を小さく制御することが求められている。

【0341】特に、鏡面反射効果によるスピバルブ膜のMR変化率の向上効果や磁歪の低減効果については、スピバルブ膜の実用性を高める上で、熱プロセスによる劣化を抑制する必要がある。

【0342】本実施形態はこのような課題に対処するために発明されたもので、熱プロセスによるMR特性の低下を抑制したスピバルブ膜を有する磁気抵抗効果素子、また実用性を考慮した上で鏡面反射効果によりMR変化率を向上させたスピバルブ膜、低磁歪を実現したスピバルブ膜、さらにはこれらの熱プロセス劣化を抑制したスピバルブ膜を有する磁気抵抗効果素子を提供することを目的としている。またさらに、そのような磁気抵抗効果素子を用いることによって、記録再生特性および実用性を向上させた磁気ヘッドおよび磁気記録装置

を提供することを目的としている。

【0343】以下、上述した課題を解決するための実施の形態について、図面を参照して説明する。

【0344】図32は、本発明の磁気抵抗効果素子(MR素子)の一実施形態の要部構造を示す断面図である。同図において、1は第1の磁性層、2は第2の磁性層である。これら第1および第2の磁性層1、2は、非磁性中間層3を介して積層されている。第1および第2磁性層1、2間は反強磁性結合しておらず、非結合型の磁性多層膜を構成している。

【0345】第1および第2の磁性層1、2は、例えばCo単体やCo合金のようなCoを含む強磁性体により構成されている。磁性層1、2はNiFe合金などで構成してもよい。これらのうち、特にバルク効果と界面効果を共に大きくすることができ、大きなMR変化量が得られるCo合金を用いることが好ましい。

【0346】磁性層1、2を構成するCo合金としては、CoにFe、Ni、Au、Ag、Cu、Pd、Pt、Ir、Rh、Ru、Os、Hfなどから選ばれる1種または2種以上の元素を添加した合金が用いられる。添加元素量は5~50原子%とすることが好ましく、さらには8~20原子%の範囲とすることが望ましい。これは、添加元素量が少なすぎるとバルク効果が十分に増加せず、逆に添加元素量が多すぎると界面効果が減少するおそれがあるからである。添加元素は大きなMR変化量を得る上で、特にFeを用いることが好ましい。

【0347】第1および第2の磁性層1、2のうち、下側の第1の磁性層1は磁気抵抗効果向上層(MR向上層)4上に形成されている。MR向上層4は下地機能を有する非磁性層(以下、非磁性下地層と記す)5上に形成されている。この非磁性下地層5は、例えばTa、Ti、Zr、W、Cr、Nb、Mo、HfおよびAlから選ばれる少なくとも1種の元素を含む層であり、これらの単体金属や合金、あるいは酸化物や窒化物などの化合物からなる。非磁性下地層5にTaなどの酸化物を用いた場合、後に詳述するように、MR向上層4で反射しきれなかった電子を非磁性下地層5/MR向上層4界面で反射させることができる。

【0348】第1の磁性層1は外部磁界により磁化方向が変化する感磁層である。一方、第2の磁性層2上には、IrMn、NiMn、PtMn、FeMn、RuRhMn、PdPtMn、MnOなどからなる反強磁性層6が形成されている。第2の磁性層2には反強磁性層6からバイアス磁界が付与され、その磁化が固着されている。すなわち、第2の磁性層2は磁化固着層である。

【0349】図32では図示されていないが、第2の磁性層の固着方法として上記のように反強磁性膜と直接接しさせて磁化方向を固着する方法の他に、第2の磁性層上にRu、Crなどの層を介して第3の磁性層を積層し、第2の磁性層と第3の磁性層をRKKY的に反強磁

性結合させて、第3の磁性層を反強磁性結合させる、いわゆるシンセティックアンチフェロ構造を用いても構わない。シンセティックアンチフェロ構造を用いることによって、バイアス点も安定になり、かつピン特性の高温下での安定性も増す。具体的には、第2の磁性層から第3の磁性層までの構成として、CoFe/Ru/CoFe、Co/Ru/Co、CoFe/Cr/CoFe、Co/Cr/Coなどが挙げられる。このときの反強磁性膜は、上述の反強磁性膜の一群と同様である。

【0350】第1および第2の磁性層1、2間に配置される非磁性層3の構成材料としては、Cu、Au、Agおよびこれらの合金、あるいはこれらと磁性元素を含む常磁性合金、Pd、Ptおよびこれらを主成分とする合金などが例示される。

【0351】反強磁性層6上には保護層7が設けられており、この保護層7は非磁性下地層5と同様な金属もしくは合金により構成されるものである。これら各層によって、この実施形態のスピンバルブ膜8が構成されている。スピンバルブ膜8にはセンス電流を供給する一対の電極（図示せず）が接続され、これらによってスピンバルブGMR素子が構成される。スピンバルブGMR素子は、感磁層1に対してバイアス磁界を印加する硬質磁性膜や反強磁性膜からなるバイアス磁界印加膜を有していてもよい。この場合、バイアス磁界は磁化固着層2の磁化方向に対して略直交する方向に印加することが好ましい。なお、図中9は基板である。

【0352】上述したスピンバルブ膜8を構成する各層のうち、MR向上層4は本発明の特徴的な部分であり、図32に示すMR向上層4は第1の金属膜4aと第2の金属膜4bとの積層膜により構成されている。スピンバルブ膜8の下地として機能する金属膜4a、4bには、例えばCu、Au、Ag、Pt、Rh、Al、Ti、Zr、Hf、PdおよびIrから選ばれる少なくとも1種の元素を含む金属膜を適用することができる。

【0353】これら複数の金属膜のうち、第1の磁性層（感磁層）1と接する第1の金属膜4aを主として構成する元素は、感磁層1を主として構成する元素と非固溶の関係にある。第2の金属膜4bについても、それを主として構成する元素が感磁層1を主として構成する元素と非固溶の関係にあることが好ましく、特にこれら第1および第2の金属膜4a、4bを主として構成する各元素が互いに固溶の関係にある場合がある。さらに、感磁層1と接する側には、例えば電子波長が短い金属からなる第1の金属膜4aが配置され、その外側に電子波長が（第1の金属膜1aより）長い第2の金属膜4bが配置されていることが望ましい。

【0354】ここで、本発明における非固溶の関係について述べる。本発明において、Aという元素とBという元素の2種類の元素が非固溶の関係を有する状態とは、2元素の相図（例えば、Binary Alloy Phase Diagram,

2nd Edition, ASM International, 1990など）において、室温程度の低温域で、Aを母材としたときにBが固溶できる原子%量と、B母材としたときにAが固溶できる原子%量がともに10%以下である元素の組み合わせを示すものとする。

【0355】具体例として、磁性層（例えば感磁層1）がCoまたはCo合金のとき、磁性層がNi合金の場合について説明する。磁性層をfcc配向にするためには下地膜がfcc金属やhcp金属であることが望ましいため、磁性層に接するMR向上層の具体的な構成元素としてはAl、Ti、Cu、Zr、Ru、Rh、Pd、Ag、Hf、Ir、Pt、Auなどが挙げられる。これらの元素のうち、Coと非固溶という上記の条件を満足する元素は、Cu、Ag、Auの3元素となる。また、Niと非固溶という上記の条件を満足する元素は、Ru、Ag、Auの3元素となる。但し、磁性層としてNi合金を用いた場合には、Cuは相図のみを参照すると固溶の関係にあるが、本発明者が実験を行った結果、MR向上層として用いた場合には、非固溶といえることが判明した。つまり、以下のような実験結果をもとに、Ni合金とCuとは非固溶と判断される。

【0356】すわち、フリー層が薄い場合には、MR向上層は前述した第1実施形態での非磁性高導電層として作用するが、非磁性高導電層とフリー層との界面で原子の拡散が生じて、diffusiveな界面になってしまうと、フリー層から非磁性高導電層に向かう電子の透過率を低下させてしまう。つまり、ピン層とフリー層の磁化方向が互いに平行な状態でも、diffusiveな界面において非弾性散乱を受けてしまうため、アップスピンの平均自由行程が長くならない。つまり、MR変化率の低下を招くことになる。この現象は、極薄フリー層と非磁性高導電層とが固溶なときに生じ、プロセスの熱処理などを行うとより顕著となる。つまり、熱処理によってMR変化率が低下する。このような現象を確認する方法をとったところ、薄いNi合金層にCuをつけた実験を行ったところ、MR変化率の低下がみられなかった。

【0357】以上の結果から、Ni合金とCuとは非固溶と判断される。従って、Ni合金と非固溶の関係を満足する元素として、本発明では、相図から得られる元素の組み合わせにCuを加えて、Ru、Ag、Au、Cuと定義することができる。このような非固溶の元素を磁性層に接して配置することによって、磁性層とMR向上層との界面の組成急峻性が熱処理などによっても失われることなく、鏡面反射効果が期待できる。

【0358】ここでは、磁性層をfcc配向させることを前提としたが、もちろん無配向や微結晶構造をもつ磁性層に対してこれらのMR向上層を用いても構わない。具体的には磁性層として、CoFeB、CoZrNb、CrにTi、Zr、Nb、Hf、Mo、Taなどが添加されたアモルファス磁性層、もしくは微結晶構造をもつ

磁性層などが挙げられる。

【0359】さらに、上記の元素によって構成されたMR向上層の一部に対して、d-スピングの制御や膜微細構造をよりの確な構造にするために、別の金属膜との積層膜にしたり、別の元素と合金化した層が、本発明によるMR向上層である。この積層される膜を構成する元素としては、fcc金属やhcp金属が望ましく、Al、Ti、Cu、Zr、Ru、Rh、Pd、Ag、Hf、Ir、Pt、Auなどが挙げられる。

【0360】MR向上層に積層膜を適用する場合、磁性層に接していない側の金属膜の好ましい例としては、磁性層に接している側の金属膜と固溶の関係を有する金属が挙げられる。ここで、Aという元素とBという元素の2種類の元素が固溶の関係を有する状態とは、上記した非固溶の場合と同様に、室温程度の低温域で、Aを母材としたときにBが固溶できる原子%量と、B母材としたときにAが固溶できる原子%量がともに10%を超える元素の組み合わせを示すものとする。

【0361】MR向上層4に積層膜を適用する際の好ましい例を示す。磁性層1がCoまたはCo合金で、金属膜4aをそれと非固溶の条件を満たすCuで構成した場合、金属膜4bは上記の固溶の条件を満たすAl、Au、Pt、Rh、Pd、Irから選ばれる少なくとも1種を含む金属膜で構成することが好ましい。金属膜4aをAgで構成した場合、金属膜4bはPt、Pd、Auから選ばれる少なくとも1種を含む金属膜で構成することが好ましい。金属膜4aをAuで構成した場合、金属膜4bはPt、Pd、Ag、Alから選ばれる少なくとも1種を含む金属膜で構成することが好ましい。磁性層1がNi合金で、金属膜4aをそれと非固溶の条件を満たすRuで構成した場合、金属膜4bは上記の固溶の条件を満たすRh、Ir、Ptから選ばれる少なくとも1種を含む金属膜で構成することが好ましい。AgおよびAuを用いる場合には、上記した通りである。

【0362】上述したような組み合わせのうち、MR向上層4を構成する2元素が10%以上互いに固溶することが望ましく、例えばAu-Cu、Ag-Pt、Au-Pd、Pt-Cu、Au-Agなどが挙げられる。なお、金属膜4aと金属膜4bの組み合わせは、必ずしも上記した固溶の関係を満たしていなければならないものではなく、例えばCu-Ru、Cu-Agの組み合わせなどを適用することも可能である。積層膜からなるMR向上層4は、第1の金属膜4aと第2の金属膜4bとの2層積層膜に限らず、3層以上の積層膜で構成することも可能である。

【0363】MR向上層4は第1の金属膜4aと第2の金属膜4bとの積層膜に限らず、例えば図33に示すように、感磁層1を主として構成する元素と非固溶の関係にある元素の合金層4cでMR向上層4を構成することもできる。この場合の合金層4cには上記した積層膜と

同様な考え方が適用できる。すなわち、磁性層1がCoまたはCo合金からなる場合には、合金層4cは主構成元素としてCu、Ag、Auの3元素から選ばれる少なくとも1種を含む。また、磁性層1がNi合金からなる場合には、合金層4cは主構成元素としてRu、Ag、Au、Cuの4元素から選ばれる少なくとも1種を含む。

【0364】合金層4cは上記した主構成元素以外に少なくとも1種の元素を含む。この主構成元素以外の元素には、2相分離膜とならないように、主構成元素と固溶の元素が用いられる。例えば、合金層4cの主構成元素にCuを用いた場合には、Cu-Au、Cu-Pt、Cu-Rh、Cu-Pd、Cu-Irなどの貴金属系の合金が用いられる。合金層4cの主構成元素にAgを用いた場合には、Ag-Pt、Ag-Pd、Ag-Auなどの貴金属系の合金が用いられる。合金層4cの主構成元素にAuを用いた場合には、Au-Pt、Au-Pd、Au-Ag、Au-Alなどの貴金属系の合金が用いられる。

【0365】上述したような合金のうち、MR向上層4としての合金層4cは2元素が10%以上互いに固溶することが望ましく、例えばAu-Cu、Ag-Pt、Au-Pd、Au-Agなどが挙げられる。このように、MR向上層4には種々の形態を適用することができ、例えば図34に示すように金属膜4aと合金層4cとの積層膜でMR向上層4を構成することも可能である。

【0366】感磁層1にCo系磁性材料を用いる場合、感磁層1の下地としてのMR向上層4はCo系磁性材料と同一のfcc結晶構造を有する金属材料や、その上の膜をfcc配向させやすいhcp構造の金属材料を用いることが好ましい。このような点からも、上述したCu、Au、Ag、Pt、Rh、Pd、Al、Ti、Zr、Hf、Irなどやそれらの合金はMR向上層4の構成材料として好適である。さらに、このような金属の積層膜もしくは合金層からなるMR向上層4を用いることによって、後に詳述するように、CoFe合金などのCo系磁性材料からなる感磁層1の磁歪を低減することができる。

【0367】MR向上層4の膜厚は、下地層としての機能を持たせるためには2nm以上とすることが望ましい。ただし、あまり厚くするとシャント分流の増大によりMR変化率が減少するため、MR向上層4の膜厚は10nm以下とすることが好ましく、さらに望ましくは5nm以下である。

【0368】上述したようなMR向上層4は、スピンバルブ膜8の耐熱性を向上させる働き、スピンバルブ膜8の鏡面反射膜（界面反射膜）としての働き、フリー層が薄い場合にもMR変化率を高い値に維持する働き、Co系磁性材料からなる感磁層1の磁歪を低減する働き、スピンバルブ膜8の結晶微細構造を制御する働きなどを有

10

20

30

40

50

するものであり、これらに基づいてスピバルブ膜 8 の MR 特性を向上させるものである。以下に、MR 向上層 4 の働きについて詳述する。

【0369】まず、スピバルブ膜の熱プロセス劣化について述べる。プロセスアニールによる MR 特性の劣化の一因として、磁性層 1、2 の非磁性中間層 3 と接していない側の鏡面反射効果がプロセスアニールにより変動することが考えられる。その様子を図 35 に示す。なお、図 35 において、 $IF_s$  はスピン依存散乱される界面、 $IF_m$  はスピン依存散乱ではなく鏡面錯乱される界面を示している。図 35 (a)、(b) は理想状態 (as-depo 時に対応) を、図 35 (c) はプロセスアニール後の状態を模式的に示している。

【0370】図 35 (a)、(b) に示すように、スピバルブ GMR の基本ユニットとなる感磁層 1 / 非磁性中間層 2 / 磁化固着層 3 の 3 層積層構造において、その両側での鏡面散乱効果が as-depo 時には生じていたものが (たとえその界面が金属膜との界面であっても)、図 35 (c) に示すように、プロセスアニールにより容易に互いに固溶するような系では界面拡散が生じ、散乱的な界面になってしまい、鏡面反射効果が弱められて、MR 特性の劣化が生じることが考えられる。

【0371】金属膜界面での鏡面反射効果は報告例自体がほとんどなく、その実証性は必ずしも確立されていないが、後述するようにポテンシャル差が小さい金属膜界面においても、理想的に鏡面反射効果が生じ得るものである。例えば、NiFe/CoFe 界面でも比較的ミキシングが少ない as-depo 状態では鏡面反射効果が得られていたものが、プロセスアニール後では固溶系にある NiFe-CoFe 界面では容易に界面拡散が生じ、界面での急峻性が失われて、MR 変化率が劣化することが考えられる。

【0372】具体的に、NiFe/CoFe 積層膜からなる感磁層を使用したスピバルブ膜では、NiFe/CoFe 界面の鏡面反射効果がプロセスアニールによって失われ、例えば as-depo 時に 7.3% であった MR 変化率が、250℃×4H のプロセスアニール後では 5.8% まで劣化してしまう。この原因としてアニールによる NiFe/CoFe 界面での鏡面反射係数の変動による MR 変化率の変動が起こったということも考えられる。

【0373】従来の考えでは、NiFe/CoFe 界面は同じ金属膜とおしの界面であり、かつ電子状態も近いため、この界面での鏡面反射は考慮されていなかったが、as-depo の状態では比較的ミキシングなどの少ない均一な界面となるため、金属膜界面においても鏡面反射効果が生じると考えられる。ところが、NiFe/CoFe は固溶の関係にあるため、プロセスアニールにより容易に界面が拡散およびミキシングし、界面での組成の急峻性が失われて鏡面反射係数が小さくなり、M

R 特性が劣化することが考えられる。逆にいうと、as-depo 状態では鏡面反射効果の分だけ MR 変化率が大きくなっていったことを意味する。

【0374】また、フリー層が薄い場合には、MR 向上層は前述した第 1 実施形態での非磁性高導電層として作用するが、非磁性高導電層とフリー層との界面で原子の拡散が生じて、diffusive な界面になってしまうと、フリー層から非磁性高導電層に向かう電子の透過率を低下させてしまう。つまり、ピン層とフリー層の磁化方向が互いに平行な状態でも、diffusive な界面において非弾性散乱を受けてしまうため、アップスピンの平均自由行程が長くならない。つまり、MR 変化率の低下を招くことになる。この現象は、極薄フリー層と非磁性高導電層とが固溶なときに生じ、プロセスの熱処理などを行うとより顕著となる。つまり、熱処理によって MR 変化率が低下する。

【0375】フリー層と非磁性高導電層との界面において、熱処理によってもアップスピンの透過を妨げることのない安定な界面を形成することが重要である。具体的には、フリー層と非磁性高導電層の材料を非固溶とすることが重要である。例えば、磁性層に Co 合金を用いたときには、非磁性高導電層の材料として、Cu、Au、Ag、Ru を挙げることができる。ここで、Cu、Au、Ag は非抵抗が低いので特に望ましい。

【0376】このようなことから、MR 特性の劣化を抑制する 1 つの実現手段として、GMR 基本ユニットの両側に、磁性層 1、2 の材料とは非固溶の金属材料を用いることが重要である。さらに、このような非固溶の金属材料層は、例えば CoFe 合金のような材料を GMR 基本ユニットに用いた場合、CoFe 合金層を fcc (111) 配向させるためのシード層としての機能も果たさなければならないため、fcc (111) 配向しやすい金属材料がよいことも分かる。加えて、感磁層に CoFe 合金を用いる場合には、磁歪制御も重要である。

【0377】プロセスアニールによる MR 特性の劣化の他の要因として、スピバルブ膜の膜微細構造の熱プロセスによる変化が挙げられる。耐熱性を向上させるために重要な膜微細構造として、感磁層 / 非磁性中間層 / 磁化固着の GMR 基本ユニットの各界面およびその両側の界面が、プロセス熱アニールを行っても安定に保てられる微細構造が望ましい。これは、感磁層 / 非磁性中間層および非磁性中間層 / 磁化固着層の界面ではスピン依存の界面散乱効果を強く引き出すためであり、また各磁性層の両側の界面については、スピン依存しない鏡面散乱効果を熱的に安定に保つために重要である。ここで、磁性層が積層膜からなる場合には、非磁性中間層に接している側の磁性膜とその外側に接している磁性膜との界面が、ここで言う鏡面散乱効果をもたらすスピン依存しない界面として考えられる。

【0378】上記したような条件を実現するために、磁

性層／非磁性層の各材料については、互いに非固溶の関係にある材料を選択することがそもそも望ましく（例えば  $\text{CoFe}/\text{Cu}$  や  $\text{Co}/\text{Cu}$ ）、そのような界面での固溶自体は起こらないはずである。従って、磁性層／非磁性層の界面、磁性層の非磁性中間層とは反対側の界面からの原子拡散を抑えることが重要になる。そのためには、GMR 基本ユニット部分の結晶（例えば  $\text{CoFe}/\text{Cu}/\text{CoFe}$  の場合には格子定数が近いので、結晶粒は各層ごとにあるのではなく、 $\text{CoFe}/\text{Cu}/\text{CoFe}$  で繋がった結晶粒となっている）は、理想的には単結晶が望ましいが、実際にはアルミナなどのアモルファス層上に形成されるスピバルブ膜で単結晶を得るのは難しい。

【0379】そこで、実用的に実現し得る結晶構造として、結晶粒界が存在したとしても通常の結晶粒界ではなく、ほとんど面内配向のすれがないうべき構造とすることが望ましい。本発明においては、上述したような MR 向上層 4 を適用することによって、サブグレインバウンダリとしての小傾角粒界を有するスピバルブ膜が再現性よく得られる。具体的には、スピバルブ膜を  $\text{fcc}$  (111) 配向させ、かつ膜面内における結晶粒間の結晶配向方向のずれを 30 度以内とすることができる。このようなスピバルブ膜の結晶粒制御により磁気抵抗効果特性の向上を図ることが可能となる。この結晶構造については後に詳述する。

【0380】さらに、例えば  $\text{CoFe}/\text{Cu}/\text{CoFe}/\text{IrMn}$  のように Mn 系反強磁性膜により磁化固着した場合、Mn が結晶粒界を通して、 $\text{CoFe}$  層を突き抜けて Cu 層まで拡散すると、MR 特性が劣化する可能性が大きい。このようなことから  $\text{CoFe}/\text{Cu}/\text{CoFe}/\text{IrMn}$  などの結晶粒界を通して、例えば Mn が Cu 層まで拡散することを抑制することが好ましい。一方、磁性層の非磁性中間層と接していない側の界面は、鏡面反射効果を引き出す界面となるので、その界面が乱れにくくなるような膜微細構造が望ましい。まず、材料的には磁性層を主として構成する元素と非固溶な関係にある材料であることが重要である。

【0381】また、 $\text{IrMn}$  のように  $\text{CoFe}$  と格子間隔の差がある反強磁性膜を用いる場合には、 $\text{CoFe}$  層とその上に成膜される  $\text{IrMn}$  層との間で大きな格子歪みが生じる。それを緩和するために、 $\text{CoFe}/\text{IrMn}$  界面で原子のディスロケーションが生じてしまう。このような界面現象を抑制する手段として、例えば  $\text{IrMn}$  層の上に  $\text{IrMn}$  の格子間隔を安定に保つ層、すなわち  $\text{IrMn}$  と同程度の格子間隔をもつ  $\text{fcc}$  金属材料を積層することが考えられる。このような構成によっても、スピバルブ膜の耐熱性を改善することができる。

【0382】さらに、反強磁性膜の下地膜として MR 向上層を用いる場合には、上記の効果の他に、反強磁性膜

の格子間隔を適切な値にして、ピン特性を向上させる効果もある。このように反強磁性膜に接しさせて MR 向上層を用いる場合でも、ピン層に直接反強磁性膜が接する通常のピン構造だけでなく、上述のような  $\text{Ru}$ 、 $\text{Cr}$  などを用いたシンセティックアンチフェロ構造であっても構わない。このように反強磁性膜と組み合わせて用いるときは、反強磁性膜と MR 向上層が熱処理によって極度に拡散しないために、MR 向上層は反強磁性膜と非固溶であるか、もしくは  $\text{IrMn}$ 、 $\text{RuRhMn}$  のような  $\gamma\text{-Mn}$  系反強磁性膜を用いたときに反強磁性膜の結晶構造を安定に保つために、 $\text{fcc}$  金属材料、 $\text{hcp}$  金属材料であることが望ましい。

【0383】本発明の磁気抵抗効果素子は、上述したような金属膜／金属膜界面の鏡面反射効果をはじめとして種々の効果に注目し、MR 特性の向上、耐熱性の改善、ピン特性の向上などを図ったものである。この際、金属膜界面を利用した鏡面反射膜では次の 2 点が特に心配される。まず第 1 に、金属膜／金属膜界面ではポテンシャルとしての差が小さいため、従来の考えに基づく反射効果としては大きな値にならないことが予想される。第 2 に、反射膜としての効果を得るためにある程度の膜厚とすると、一般に金属膜は抵抗が小さいため、シャント分流により GMR 基本ユニットに流れる電流が小さくなり、MR 変化率が小さくなることが予想される。

【0384】金属膜は反射膜としてだけ見たときには酸化物よりは劣ると考えられる。しかしながら、金属反射膜の反射効果としては酸化物膜よりは劣るものの、良好な反射効果を得ることができ、さらに実用性という点で考えた場合には、酸化物反射膜に比べて金属反射膜は大きなメリットをもたらすものである。本発明はこのようにな点に着目してなされたものである。

【0385】ここで、金属膜／金属膜界面で十分良好な鏡面反射効果が得られることを示したモデルを図 3.6 に示す。なお、ここでは通常用いる電子ポテンシャルによる説明の変わりに、波動論による非常に単純化したモデルを考えると理解しやすい。図 3.6 に示すように、あるフェルミ波長をもつ電子が金属膜界面にきたときに、電子は波長の変化を伴うことになる。このときに、反射膜 p に相当する金属膜でのフェルミ波長のほうが短いならば、電子はある臨界角度  $\theta_c$  よりも低角に入射したものは ( $\theta_c > \theta$ ) は全反射されることになる。反射膜 p 内でのフェルミ波長と、反射膜 p に接している金属膜でのフェルミ波長の差が大きいほど、その臨界角度  $\theta_c$  は大きくなり、伝導に寄与する全ての電子にとって平均した反射率 p は大きくなる。

【0386】図 3.7 および図 3.8 に、反射膜 p のフェルミ波長  $\Lambda(p)$  と反射膜 p と接する GMR 膜フェルミ波長  $\Lambda(\text{GMR})$  との比 ( $\Lambda(\text{GMR})/\Lambda(p)$ ) と、臨界角度  $\theta_c$  との関係の例を示す。図 3.7 および図 3.8 から分かるように、具体的な数値としてはそれ程大きな

10

20

30

40

50

電子波長の差がなくても十分な反射が生じる。もちろん、絶縁膜による反射膜では電子波長が無限度と考えられるので、臨界面角度 $\theta$ も大きくなるが、金属膜／金属膜界面であっても十分な反射が生じる。図38はAu (Ag)／Cu界面で鏡面反射を起こす臨界面角度 $\theta$ を単純にフェルミ波長から算出したグラフである。図38から分かるように、Au (Ag)／Cu界面でも十分に鏡面反射が起こる。

【0387】以上のことから、金属膜で反射膜を構成する場合、(1)フェルミ波長ができるだけ長い金属膜で、(2)膜界面での組成急峻性が高い、ということが重要となることが分かる。フェルミ波長は通常数オングストロームのオーダーなので、それよりも界面拡散が生じて組成急峻性が失われると、波の反射は波長が適応して変化してしまい、透過する確率が高くなると考えられる。よって、いかにして金属膜界面での組成急峻性が高く、急激にその界面でフェルミ波長が変わらなければならないようになっていくかが重要である。ただし、

(1)については鏡面反射との相関は分かっておらず、フェルミ波長の算出も難しく、必ずしも必要な条件かどうかは不明である。ここで、特に(2)を満足するような条件は必要不可欠であると本発明者らは推測した。

【0388】(2)を満足させる1つの大きな指針として、金属膜／金属膜同士が互いに非固溶な関係にあることが特に重要である。アニールによって膜界面への析出が起こりやすい系だと、ますます膜界面での組成急峻性が高くなり、反射が生じやすくなることが予想される。電子のフェルミ波長がそもそも数オングストロームのオーダーなので、膜界面での組成急峻性もそのオーダーでフラットであることが望ましい。また、上記した(1)の点に関しては、反射効果を強く引き出すために、磁性層の外側に電子波長の短い金属膜を配置し、その外側に電子波長が長い金属膜を配置することが好ましい。

【0389】以上のことから、金属膜／金属膜界面で鏡面反射効果をより現実的に引き出す際の材料選択の指針としては、MR向上層として磁性層と非固溶な金属層を磁性層のスペーサ層とは反対側の面と接するように配置することである。加えて、例えば感磁層1の外側に電子波長の短い第1の金属膜4aを配置し、その外側に電子波長が長い第2の金属膜4bを配置することが好ましい。

【0390】さらに、反射膜として合金膜を用いると、一般的に完全な規則合金を形成しない限り、抵抗が純金属よりも大きくなる。つまり、電子波長が長くなることになる。これは反射膜としてみた場合には有利になると同時に、非固溶の関係を保っているという点でも有利である。このような合金膜を用いる方法として、合金膜を直接成膜する方法に限らず、互いに合金を作る系の膜を積層して成膜し、その積層界面に合金を生成する方法であってもよい。ただし、フリー層が薄い場合には、フリ

ー層に接するMR向上層（フリー層が薄い場合には、第1実施形態における非磁性高導電層として作用する）の比抵抗は低いほうが好ましいので、合金層を直接フリー層に接させることは逆に望ましくない。

【0391】以上のことから、図32、図33および図34に示したスピバルブ膜8では、反射膜として用いるMR向上層4に、磁性層（感磁層1）とは非固溶の関係を有する金属膜（具体的には第1の金属膜4a）を磁性層（感磁層1）と接して配置し、さらに反射膜としてのMR向上層4を複数の金属膜4a、4bの積層膜で形成する、あるいはMR向上層4を合金層4cで形成するという構成を採用している。複数の金属膜4a、4bや合金層4cの構成材料は、前述した指針に基づいて選択する。さらに、積層膜でMR向上層4を構成する場合、これらのうち電子波長の短い第1の金属をMR向上層4側に配置することが好ましい。これら以外の構成条件についても、前述した指針に基づくものである。

【0392】上述した鏡面反射効果に基づくMR変化率は、前述したように、プロセスアニール後においても保たれるものである。これはMR向上層4の材料選択（非固溶の関係など）によって、界面の組成急峻性がプロセスアニール後においても保持されるためである。言い換えると、従来のスピバルブ膜ではプロセスアニールにより界面での拡散やミキシングにより損われていたMR特性が、本発明によればプロセスアニール後においても良好に保つことができる。このように、本発明のスピバルブ膜8は耐熱性に優れるものである。

【0393】なお、従来技術に示した(e)の構成におけるCu／Ag積層膜は、Cu膜単層では表面凹凸が大きいため、Ag膜を膜表面にして積層にすることによって、膜表面での鏡面反射効果を引き出したものである。これは本発明における金属膜／金属膜界面で鏡面反射効果を強く引き出すための構成とは明らかに異なるものである。つまり、膜表面での平坦化技術（従来技術）と、膜界面の組成急峻性を高める技術（本発明）とは、その上に積層される材料まで考慮すれば明らかに異なるものである。

【0394】MRの耐熱性に効果を発揮するMR向上層は、鏡面反射膜としての効果のみならず、前述したように膜微細構造の制御を可能にすることによって、スピバルブ膜8のMR特性の向上に寄与している。このようなMR向上層の機能は、感磁層1の下側に配置した場合に限らず、例えば図39や図40に示すように、反強磁性層6上に配置した場合（MR向上層4B）にも発揮されるものである。この場合の効果は感磁層の磁歪には直接的には関係せず、前述したようにIrMnなどからなる反強磁性層6上に前述した複数の金属膜4a、4bの積層膜や合金層4cからなるMR向上層4Bを配置することによって、反強磁性層6の格子間隔を安定に保つことができる。これによって、磁性層2／反強磁性層6界

面でのディスロケーションが抑制され、スピバルブ膜 8 の耐熱性がより一層向上する。

【0395】さらに他のピン特性も、反強磁性膜が適切な格子間隔に制御されることによって向上する。格子間隔の制御という意味でより効果的なのは、MR 向上層が反強磁性膜の下地膜として用いられる場合であり、いわゆる反転構造のスピバルブ膜またはデュアルスピバルブ膜などとして用いられるときに特に有効である。このときでも本発明による fcc 金属または hcp 金属膜の積層膜、もしくは合金膜によって反強磁性膜の格子間隔を適切な値に自由自在に制御でき、ピン特性の様々な特性（交換バイアス磁界、耐熱性）などを向上させることができる。

【0396】複数の金属膜 4a、4b の積層膜からなる MR 向上層 4B を反強磁性層 6 上に配置する場合、Au などの表面エネルギーが小さい金属からなる第 2 の金属膜 4b は、反強磁性層 6 側に配置することが好ましい。すなわち、Au や Ag などからなる第 2 の金属膜 4b が Ta などからなる保護層 7 と接するように配置すると、Au や Ag などが保護層 7 に拡散して耐熱性が低下するおそれがあるため、Cu などからなる第 1 の金属膜 4a を保護層 7 側に配置することが好ましい。また、反強磁性層 6 上の MR 向上層 4B は、第 1 の金属膜 4a / 第 2 の金属膜 4b / 第 1 の金属膜 4a というような積層膜で構成してもよい。

【0397】前述したように、金属材料の積層膜や合金層からなる MR 向上層 4A は、Co や CoFe 合金などの Co 系磁性材料からなる感磁層 1 の磁歪低減に対して効果を発揮する。つまり、Cu 下地層単独では感磁層 1 としての CoFe 合金単層の格子間隔が小さすぎるため、 $-1 \text{ ppm}$  を超える負の磁歪となる。一方、Au 下地層単独では感磁層 1 としての CoFe 合金単層の格子間隔が大きすぎて、 $+1 \text{ ppm}$  を超える正の磁歪となる。

【0398】これに対して、Cu、Au、Ag、Pt、Rh、Pd、Al、Ti、Zr、Hf、Ir から選ばれる少なくとも 1 種の元素を含む金属膜の積層膜、あるいは合金層 4c からなる MR 向上層 4 を、感磁層 1 としての CoFe 合金の下地とすることによって、Co や CoFe 合金などの Co 系磁性材料の fcc (111) 配向させた上で、低磁歪に有効な格子間隔、すなわち  $d(111)$  格子間隔を  $0.2055 \sim 0.2085 \text{ nm}$  の範囲とすることができる。感磁層 1 の下地としての MR 向上層 4 は、fcc-d(111) が  $0.2058 \text{ nm}$  より大きいことが好ましい。d-(111) 格子間隔を適切な値に制御する方法としては、例えば Au-Cu 積層膜、Au-Cu 合金膜を用いた場合、積層膜では Au と Cu の積層膜の膜厚比を変える、合金膜では Au と Cu の組成比を変えることなどが挙げられる。

【0399】Au-Cu 合金の具体的な組成は、 $\text{Au}_{25}$  50

$\text{Cu}_{75} \sim \text{Au}_{75}\text{Cu}_{25}$  (原子%) の範囲とすることが好ましい。また、合金層と金属膜との積層膜を使用する場合には、Au-Cu 合金単独で用いる場合より若干 Au リッチな組成、すなわち  $\text{Au}_{25}\text{Cu}_{75} \sim \text{Au}_{95}\text{Cu}_5$  (原子%) の組成とすることが好ましい。

【0400】図 32、図 33 および図 34 は、感磁層 1 を下置としたスピバルブ膜 8 について示したが、本発明はこれに限られるものではなく、例えば図 43 や図 44 に示すように、感磁層 1 を上置とした反転構造のスピバルブ膜 8 やデュアルエレメントタイプのスピバルブ膜に対して適用することもできる。特に、反転スピバルブ膜やデュアルスピバルブ膜のときには、反強磁性膜の下地膜としての MR 向上層としての役割でも大きな効果を発揮する。

【0401】図 41 および図 42 に示すスピバルブ膜 8 は、基板 9 側から順に、非磁性下地層 5 / MR 向上層 4 / 反強磁性層 6 / 磁化固着層 2 / 非磁性中間層 3 / 感磁層 1 / MR 向上層 4 / 保護層 7 が積層された構造を有している。図 41 は MR 向上層 4 に合金層 4c を用いた例であり、図 42 は MR 向上層 4 に複数の金属膜 4a、4b の積層膜を用いた例である。また、図 34 と同様に、金属膜 4a と合金層 4c との積層膜を用いることもできる。

【0402】図 42 に示したように、感磁層 1 と接する MR 向上層 4 に積層膜を適用する場合、図 39 に示した上側の MR 向上層 4 と同様に、保護層 7 側には Cu などからなる第 1 の金属膜 4a を配置することが好ましい。従って、図 42 に示した感磁層 1 側の MR 向上層 4 は、第 1 の金属膜 4a / 第 2 の金属膜 4b / 第 1 の金属膜 4a の積層膜で構成している。

【0403】反転構造の場合の反強磁性膜の下地の MR 向上層は膜成長の制御を行い、格子間隔の制御、膜微細構造の制御により耐熱性、ピン特性を向上させるものであり、感磁層の磁歪制御、鏡面反射効果の向上などとは異なるものである。よって、反強磁性膜の膜微細構造を良好にできる成膜条件であれば、反強磁性膜の下地側には MR 向上層なしの場合や、Ta、Ti などの通常よく用いられるバッファ層上に反強磁性膜を成膜する、通常の反転構造の下地構造を適用した場合においても、感磁層側の MR 向上層のみでも十分効果を発揮する。

【0404】反転構造のスピバルブ膜 8 においても、感磁層 1 に接して上記したような MR 向上層 4 を配置することによって、感磁層 1 と MR 向上層 4 との界面の組成急峻性などに基づく鏡面反射効果により MR 特性の向上を図ることができる。そして、前述したように、鏡面反射効果に基づく MR 変化率はプロセスアニール後においても保たれるため、良好な耐熱性を得ることが可能となる。

【0405】なお、上述した反転構造のスピバルブ膜 8 においては、感磁層 1 / MR 向上層 4 界面、さらには

MR向上層4内の第1の金属膜4a/第2の金属膜4b界面や第2の金属膜4b界面(図42)で反射を起こさせるものであり、従来技術として示した(e)の構成のCu/Ag積層膜において、Ag膜表面で反射を生じさせていたものとは構成が異なる。従来技術として示した(d)の構成でAu膜表面にTaを積層すると反射効果が失われるという問題も、本発明では解決している。本発明では金属膜/金属膜界面での鏡面反射効果を利用し、電子のフェルミ波長の大きさを考慮した膜厚と、非固溶の概念を用いているためである。

【0406】従来技術として示した(d)の構成では、僅か0.4nmというフェルミ波長と同程度の極薄のAu層上に、Auと固溶系であるTaを積層しているため、たとえCo-Au界面で反射が生じていたとしても反射効果が失われることは明白である。Au膜の膜厚がフェルミ波長よりも厚くした場合には、Taとの拡散界面の影響も小さくなるため、反射効果が得られるようになる反面、シャント分流による悪影響が大きくなる。従って、Au/Ta界面に代えてAu/Cu/TaのようにTaとは非固溶の関係にあるCu層を介在させた積層膜を使用した場合にはAu膜界面を乱すことはない。さらに、極薄のCu層を例えばCoFeとAuとの界面に挿入することによって、Auの非磁性中間層への長期的な拡散を抑えると同時に、一旦フェルミ波長が短い層を介してからAu層を配置することで、反射効果を増大させることができる。

【0407】上述した各実施形態においては、MR向上層4を感磁層1や反強磁性層6と接して配置する場合について説明したが、MR向上層4は例えば図43に示すように、感磁層1や磁化固着層4内に配置した場合にも

前述した実施形態と同様な効果を得ることができる。

【0408】図43に示すスピバルブ膜8において、感磁層1は例えばNiFe層1aとCoFe層1bとにより構成されており、これらの間に複数の金属膜4a、4bの積層膜からなるMR向上層4が介在されている。NiFe層1aとCoFe層1bとは、MR向上層4を介して磁氣的に結合(強磁性結合)されており、磁氣的には感磁層1として一体的に振る舞う。このように、NiFe層1a/CoFe層1b界面に両者と非固溶のMR向上層4を挿入する場合、NiFe層1aとCoFe層1bは一体となって感磁層1として働かなければならないので、挿入するMR向上層4は薄くしなければならない。また、磁化固着層2内にMR向上層4を介在させることもでき、その場合磁化固着層2を構成する1つ以上の磁性膜は、強磁性結合もしくは反強磁性結合により磁氣的に結合される。強磁性結合か反強磁性結合かはMR向上層4の材料、膜厚によって決まる。

【0409】上述した各実施形態の磁気抵抗効果素子は、例えば図44や図45に示すような録再分離型磁気ヘッドに再生素子部として搭載される。なお、本発明の

磁気抵抗効果素子は磁気ヘッドに限らず、磁気抵抗効果メモリ(MRAM)などの磁気記憶装置に適用することも可能である。

【0410】図44および図45は、本発明の磁気抵抗効果素子を再生素子部に適用した録再分離型磁気ヘッドの実施形態の構造をそれぞれ示す図であり、これらの図は録再分離型磁気ヘッドを媒体対向面方向から見た断面図である。

【0411】これらの図において、21はAl<sub>2</sub>O<sub>3</sub>層を有するAl<sub>2</sub>O<sub>3</sub>・TiC基板などの基板である。このような基板21の主表面上には、NiFe合金、FeSiAl合金、非晶質CoZrNb合金などの軟磁性材料からなる下側磁気シールド層22が形成されている。下側磁気シールド層22上には、AlO<sub>x</sub>などの非磁性絶縁材料からなる下側再生磁気ギャップ23を介してスピバルブGMR膜24が形成されている。このスピバルブGMR膜24として、前述した各実施形態のスピバルブ膜8が使用される。

【0412】図44において、スピバルブGMR膜24は所望のトラック幅となるように、記録トラック幅から外れた外側領域を例えばエッチング除去した形状とされている。このようなスピバルブGMR膜24のエッジ部の外側には、それぞれスピバルブGMR膜24にバイアス磁界を印加するバイアス磁界印加膜25が配置されている。一対のバイアス磁界印加膜25は、スピバルブGMR膜24のエッジ部とアバット接合している。

【0413】一対のバイアス磁界印加膜25上には、Cu、Au、Zr、Taなどからなる一対の電極26が形成されている。スピバルブGMR膜24には、一対の電極26からセンス電流が供給される。これらスピバルブGMR膜24、一対のバイアス磁界印加膜25および一対の電極26は、GMR再生素子部27を構成している。GMR再生素子部27は、上述したようにいわゆるアバットジャンクション構造を有している。

【0414】また、図45においては、スピバルブGMR膜24と下側再生磁気ギャップ23との間に、予めトラック幅から外れた領域にスピバルブGMR膜24にバイアス磁界を印加する一対のバイアス磁界印加膜25が形成されている。この一対のバイアス磁界印加膜25は所定の間隙をもって配置されており、その上にスピバルブGMR膜24の再生トラックの外側部分が積層形成されている。スピバルブGMR膜24は、その両端部にみをそれぞれバイアス磁界印加膜25上に積層するようにしてもよい。

【0415】スピバルブGMR膜24上には、一対の電極26が形成されている。スピバルブGMR膜24の実質的な再生トラック幅は、一対の電極26の間隔によって規定されている。これらスピバルブGMR膜24、一対のバイアス磁界印加膜25および一対の電極2

6は、オーバーレイ構造のGMR再生素子部27を構成している。

【0416】図44および図45において、GMR再生素子部27上には下側再生磁気ギャップ23と同様な非磁性絶縁材料からなる上側再生磁気ギャップ28が形成されている。さらに、上側再生磁気ギャップ28上には、下側磁気シールド層22と同様な軟磁性材料からなる上側磁気シールド層29が形成されている。これら各構成要素によって、再生ヘッドとしてのシールド型GMEヘッド30が構成されている。

【0417】記録ヘッドとして薄膜磁気ヘッド31は、シールド型GMEヘッド30上に形成されている。薄膜磁気ヘッド31の下側記録磁極歯、上側磁気シールド層29と共通の磁性層により構成されている。シールド型GMEヘッド30の上側磁気シールド層29は、薄膜磁気ヘッド31の下側記録磁極を兼ねている。この上側磁気シールド層を兼ねる下側記録磁極29上には、AlO<sub>2</sub>などの非磁性絶縁材料からなる記録磁極ギャップ32と上側記録磁極33が順に形成されている。媒体対向面より後方面には、下側記録磁極29と上側記録磁極33に記録磁界を付与する記録コイル（図示せず）が形成されている。

【0418】上述した再生ヘッドとしてのシールド型GMEヘッド30と記録ヘッドとして薄膜磁気ヘッド31とによって、録再分離型磁気ヘッドが構成されている。このような録再分離型磁気ヘッドはヘッドスライダに組み込まれ、例えば図46に示す磁気ヘッドアッセンブリに搭載される。図46に示す磁気ヘッドアッセンブリ60は、例えば駆動コイルを保持するボビン部などを有するアクチュエータアーム61を有し、アクチュエータアーム61の一端にはサスペンション62が接続されている。

【0419】サスペンション62の先端には、上述した実施形態の録再分離型磁気ヘッドを具備するヘッドスライダ63が取り付けられている。サスペンション62は信号の書き込みおよび読み取り用のリード線64が有し、このリード線64とヘッドスライダ63に組み込まれた録再分離型磁気ヘッドの各電極とが電氣的に接続されている。図中65は磁気ヘッドアッセンブリ60の電極パッドである。

【0420】このような磁気ヘッドアッセンブリ60は、例えば図47に示す磁気ディスク装置などの磁気記録装置に搭載される。図47はロータリーアクチュエータを用いた磁気ディスク装置50の概略構造を示している。

【0421】磁気ディスク51はスピンドル52に装着され、駆動装置制御源（図示せず）からの制御信号に応答するモータ（図示せず）により回転する。磁気ヘッドアッセンブリ60は、サスペンション62の先端に取り付けられたヘッドスライダ63が、磁気ディスク51上

を浮上した状態で情報の記録再生を行うように取り付けられている。磁気ディスク51が回転すると、ヘッドスライダ63の媒体対向面（ABS）は磁気ディスク51の表面から所定の浮上量（0以上100nm以下）をもって保持される。

【0422】磁気ヘッドアッセンブリ60のアクチュエータアーム61は、リニアモータの1種であるボイスコイルモータ53に接続されている。ボイスコイルモータ53は、アクチュエータアーム61のボビン部に巻き上げられた図示しない駆動コイルと、それを挟み込むように対向して配置された永久磁石および対向ヨークからなる磁気回路とから構成される。アクチュエータアーム61は、固定軸54の上下2カ所に設けられた図示しないボールベアリングによって保持され、ボイスコイルモータ53により回転撓動が自在にできるようになっている。

【0423】なお、以上の実施形態では録再分離型磁気ヘッドを用いて説明したが、記録ヘッドと再生ヘッドで共通の磁気ヨークを用いる録再一体型磁気ヘッドなどの他のヘッド構造に本発明の磁気抵抗効果素子を適用することも可能である。さらに、本発明の磁気抵抗効果素子は磁気ヘッドに限らず、磁気抵抗効果メモリ（MRAM）などの磁気記憶装置に適用することもできる。

（実施例）次に、本発明の具体的な実施例およびその評価結果について述べる。

（実施例1）この実施例1では、Ta（5nm）/Au（1nm）/Cu（1nm）/CoFe（4nm）/Cu（2.5nm）/CoFe（2.5nm）/IrMn（7nm）/Ta（5nm）構造のスピバルブ膜を、DCナグネトロンスパッタにより作製した。成膜時の真空度は $1 \times 10^{-7}$  Torr以下で、アルゴン圧は2~10mTorrとした。基板は熱酸化シリコン基板を用いた。なお、磁気ヘッドの作製時には、アルチック基板上のAl<sub>2</sub>O<sub>3</sub>ギャップ上に成膜することになるが、特性は変わらないことが確認されている。

【0424】上記したスピバルブ膜は、as-dep状態のMR変化率が9.6%で、250℃×4Hのプロセスアニール（アニール条件：250℃×4H、磁場5kOe）後においてもMR変化率は9.0%を維持していた。磁歪は $\sim \pm 10^{-6}$ 以下のオーダーの値が得られた。H<sub>k</sub>についても、容易軸方向に磁場を加えたままのアニール上がりH<sub>k</sub>を飽和H<sub>k</sub>と定義すると、飽和H<sub>k</sub>で約8Oeと小さく、軟磁性も実現できていた。また、容易軸方向のH<sub>c</sub>も0~3Oeと小さかった。

【0425】ここで、MR向上層はAu/Cu積層膜であり、AuとCuの界面は合金を形成している。CuとCoFeの界面は非固溶な界面である。TaとAuは固溶する界面であるが、Au/Cuが電子波長に比べて十分長い距離の膜厚を有するため、反射は十分それまでの界面で生じており、ここに固溶関係にある界面が存在し

ていても問題ない。fcc構造のAu/Cu下地層の効果によって、CoFeはfcc(111)配向している共に、CoFeのd(111)スペーシングの大きさは0.2074nmと磁歪的にも小さな値に制御されている。

【0426】この実施例1のスピナル膜を断面TEMにより観察した。その結果、Au/Cu下地上にCoFe/Cu/CoFeのGMR基本ユニット部分が1原子層ずつきれいに層状成長しており、fcc(111)配向していることが確認された。また、感磁層としてのCoFe層部分のマイクロディフラクションでは、fcc-d(111)スペーシングの大きさは0.2074nmと磁歪的にも好適な値になっていた。さらに、このスピナル膜のXRDパターンを図48に示す。X線回折でもCoFeのfcc-d(111)スペーシングが0.2074nmであることが分かる。

【0427】なお、図48のXRDプロファイルにおいて、ピーク1, 2, 3はIrMnに相当するピークであり、ピーク4はCoFe/Cu/CoFe積層膜のfcc(111)ピークと考えられ、感磁層のみのd-スペーシングを求めるのは困難である。この場合には、ピーク4のd-スペーシングを感磁層のd-スペーシング値とする。

【0428】上述したAu(1nm)/Cu(1nm)下地に代えて、Cu(2nm)も単独で用いるとCoFeのfcc-d(111)スペーシングは0.2054nmと小さくなり、磁歪は負側に大きくなる。一方、Au(2nm)を単独で用いるとCoFeのfcc-d(111)スペーシングは0.2086nmと大きくなり、磁歪は正側に大きくなる。このようにAu/Cu下地を用いることによって、初めて好適な0.2074nmのスペーシングが得られる。

【0429】なお、従来技術で示した(g)の構成のCu膜上では得られなかった耐熱性が、Au/Cu積層膜で得られた1つの要因として、磁歪にも影響している格子間隔の違いが挙げられる。Cu下地では格子間隔が狭くなり、IrMnとの界面での格子不整合が大きくなり歪みが大きくなる。この歪みが大きい状態でプロセスアニールを行うことにより歪み緩和が生じ、特に固着層と反強磁性膜の界面で拡散を生じさせることになるからである。よって、この影響はIrMnの膜厚が厚いほど顕著になる。ところが、Au/Cu下地の方がIrMnの格子間隔と近いので、その上に積層されるCoFe/Cu/CoFeが逆にIrMnに近い格子定数の歪み格子となり、アニールによる歪み緩和の影響が小さくなるからである。また、従来技術の(h)の構成のAu下地の場合には、逆に格子間隔が広すぎ、CoFe/Cu/CoFeの歪みエネルギーが大きくなりすぎて、逆に界面のディスロケーションが生じやすくなり、初期アニール劣化が生じてしまう。Au層とCoFe層とを直接積層

すると、Au層が結晶粒界に沿って非磁性中間層のCu層にまで拡散する可能性があるからである。非磁性中間層にAuが到達するとMR変化率はとたんに小さくなる。これは長期耐熱性に影響してくる。ところが、Au/Cu積層膜にすることによって、Cu層がAu拡散のストッパ層となり長期耐熱性も安定となる。

【0430】下地としてのTaはAuを二次元的に成長させるために必要なバッファ層である。AuをアモルファスAl<sub>2</sub>O<sub>3</sub>上に直接成膜した場合には、Auがアイランド成長し、スペーサ層を介して固着層と感磁層との強磁性的結合の結果、H<sub>in</sub>の増大原因となる。また、実際の素子ではプロセスを経た基板上への成膜となるため、安定して成膜を行うためにバッファ層が必要である。ここではTaを下地膜に用いたが、Ti、Zr、Cr、W、Hf、Nb、もしくはこれらを含む合金、これらの金属を含む酸化物や窒化物であってもよい。

【0431】このように、従来技術の構成(f)のように、Auの下地膜として合計220nmもの層を用いなくても、Ta下地を使用することによって、十分Auのアイランド成長を妨げ平坦な膜表面を得ることができ、その上に成膜されるCu/CoFe膜の界面も平坦となる。また、350℃もの高温の熱処理をする必要もない。最適なのは270℃×4H程度の熱処理を行うことであり、最も組成急峻性を保った界面を形成することができる。このようにTaなどの非磁性下地層は重要であり、通常用いられている下地層との組み合わせにより平坦なAu膜が得られる。

【0432】また、非磁性下地層としてTi(5nm)、Zr(5nm)、W(5nm)、Cr(5nm)、V(5nm)、Nb(5nm)、Mo(5nm)、Hf(5nm)、およびこれらの合金(5nm)を用いた場合においても、同様な効果が得られた。さらに、MR向上層としてAu(0.5~2nm)/Cu(0.5~2nm)、Au(0.3~1nm)/Cu(0.3~1nm)/Au(0.3~1nm)/Cu(0.3~1nm)、AuCu(0.5~5nm)/Cu(0.5~2nm)を用いた場合においても、同様な効果が得られた。

【0433】このように、MR向上層は2層から構成されていても、またそれ以上の層数であっても、さらに合金層であれば1層であっても構わない。ただし、抵抗を上昇させる添加元素が加えられていない場合には、膜厚が厚くなるとシャント分流が増大するため、5nm以下であることが望ましい。しかし、下地としてfcc配向させるシード効果もなければならぬので、磁性層の下に位置する場合のMR向上層の膜厚としては2~5nm程度が望ましい。

【0434】上記のAu-Cuの組み合わせ以外の積層膜、合金膜材料の組み合わせとしては、磁性層がCo系合金のときには、Ru-Cu、Au-Cu、Pt-C

u、Rh-Cu、Pd-Cu、Ir-Cu、Ag-Pt、Ag-Pd、Ag-Au、Au-Pt、Au-Pd、Au-Alなどが挙げられる。これらの組み合わせのうち、Co系磁性層に接するMR向上層の主元素はCu、Au、Agのいずれかである。

【0435】膜構成に関しては、Au-Cuの場合の前述のように、2層積層膜でも、3層積層でも、さらに層数が多くても、合金層の場合には1層であってもそれ以上の層数であっても構わない。膜厚に関しても前述のAu-Cuのときと同様であり、第3の添加元素がない場合にはトータル膜厚で2～3nm程度が望ましい。

【0436】Co系のときの以上の組み合わせのうち、特に膜微細構造の点でも望ましいのが、互いに大きく固溶する組み合わせのAu-Cu、Ag-Pt、Au-Pd、Au-Ag、Pt-Cuなどが特に望ましい。このなかであとは適当な格子定数に制御し得る組み合わせで最適な材料が決定される。

【0437】上記の磁性層がCu系のときと全く同様に、磁性層がNi系のときにはそれに接するMR向上層の積層膜、またはMR向上層の合金膜の組み合わせとして、Au-Pt、Au-Pd、Au-Ag、Au-Al、Ag-Pt、Ag-Pd、Ru-Rh、Ru-Ir、Ru-Ptなどが挙げられる。これらの組み合わせのうち、Ni系磁性層に接する側のMR向上層の主元素は、Au、Ag、Ruのいずれかである。膜構成、膜厚に関しては全く同様である。

【0438】さらに、MR向上層を形成する2つの元素の組み合わせとして、互いに非固溶であってもよく、例えば磁性層がCo系磁性層の場合には、Cu-Ru、Cu-Agの積層膜であっても構わない。これらの非固溶な組み合わせの場合には合金層を形成しようとしても、2相分離してしまうので好ましくなく、積層膜で用いるのが好ましい。ここで、磁性層がNi系磁性層の場合の具体例として、NiFe、NiFeCr、NiFeNb、NiFeRhなどが挙げられる。

【0439】またピン膜構成として、ここでは単純に反強磁性膜にピン層が直接積層されているタイプのものを示したが、シンセティックアンチフェロ構造でも構わない。例えばピン膜構成として、CoFe 2.5nm/IrMn 7nmの代えて、CoFe 3nm/Ru 0.9nm/CoFe 3nm/IrMn 7nm、CoFe 3nm/Cr 0.9nm/CoFe 3nm/IrMn 7nmなどでも構わない。

【0440】反強磁性膜は、PtMn、NiMn、RuRhMn、CrMn、FeMn、NiOなどの材料でも構わない。ピン層材料はCoでもNiFeでも構わない。

【0441】上記した非磁性下地層はTaなどの金属膜に限らず、例えばTaO<sub>2</sub>のような酸化膜を使用することもでき、Taに代えてTaO<sub>2</sub>、下地を用いた場合に

も、同様に良好な効果が得られた。この場合、MR向上層で反射しきれなかった電子をポテンシャル差が大きいTaO<sub>2</sub>下地/MR向上層界面で反射させることができ、MR変化率をさらに向上させることができる。ただし、TaO<sub>2</sub>下地層上に直接CoFeを成膜するとfcc(111)配向しなかったり、また磁歪的に望ましいfcc-d(111)スペーシングは得られない。これに対してTaO<sub>2</sub>/Au/Cu下地は実用性に優れるものである。TaO<sub>2</sub>に代えてTi、Zr、Cr、W、Hf、Nbなどの酸化物を用いることもできる。また、TiN、Ta<sub>2</sub>Nのような窒化物を用いることもできる。

(実施例2) この実施例2では、Ta(5nm)/Au(1nm)/Cu(1nm)/CoFe(4nm)/Cu(2.5nm)/CoFe(2.5nm)/IrMn(7nm)/Au(0.5nm)/Cu(0.5nm)/Ta(5nm)構造のスピンバルブ膜を、実施例1と同様にして作製した。

【0442】上側のMR向上層としてのAu/Cu積層膜の格子定数は、CoFe/Cu/CoFe積層膜の格子定数よりIrMnに近いので、IrMn上にAu/Cu積層膜を形成することによって、IrMnの格子定数をより安定に保つことができ、熱安定性をより一層高めることができる。Au層を保護膜のTa直下に配置すると、Auのような表面エネルギーの小さな層が、Taのような表面エネルギーの大きな層の直下に存在することになるので、AuがTa表面へ拡散しやすく、層の熱安定性が劣化する。よって、Ta直下にはAuやAgなどは配置しないほうが望ましい。この実施例のようにCu層を介してTa保護膜を形成するほうが好ましい。Au/Cu合金層でも同様な効果が得られる。

(実施例3) この実施例3では、Ta(5nm)/NiCoFe(5nm)/Au(1nm)/Cu(1nm)/CoFe(3nm)/Cu(2.5nm)/CoFe(2.5nm)/IrMn(7nm)/Ta(5nm)構造のスピンバルブ膜を、実施例1と同様にして作製した。このスピンバルブ膜において、感磁層はAu/Cu膜が介在されたNiCoFe(5nm)とCoFe(3nm)との積層膜である。

【0443】また、本発明との比較例として、Ta(5nm)/NiCoFe(5nm)/CoFe(3nm)/Cu(2.5nm)/CoFe(2.5nm)/IrMn(7nm)/Ta(5nm)構造のスピンバルブ膜を同様にして作製した。

【0444】比較例のスピンバルブ膜は、as-beepoでMR変化率8.6%であったものが、250℃×4Hのプロセスアニール後には6.6%と劣化し、劣化率は23%にも達した。これはCoFeとNiFeCrが固溶系であるため、as-beepo段階ではさほどCoFe/NiFeCr界面でミキシングせずにMR変化率がでている。しかし、250℃×4H程度のアニールを

行くと、CoFe/NiFeCr界面が容易に乱れてしまう。これはシャント化のためにNiFeにCrを4%程度添加したNiFeCrでの結果だが、Ni<sub>81</sub>Fe<sub>19</sub> (原子%)でも同様である。

【0445】一方、実施例3のようにAu/Cu積層膜を挿入することにより、CoFe層とNiFeCr層との拡散が抑えられるため、MR変化率はas-depo段階で8.7%であったものが、250℃×4Hのプロセスアニール後でも8.1%とMR劣化が著しく抑えられた。これはAu/Cu挿入による拡散防止の効果として、CoFe層との界面反射効果がアニール後も保たれていることが挙げられる。

【0446】Au (1nm)/Cu (1nm) に代えて、Au (0.5nm)/Cu (0.5nm)、Cu (0.5nm)/Au (0.5nm)、Au (0.3nm)/Cu (0.3nm)/Au (0.3nm)、Au (0.3nm)/Cu (0.3nm)/Au (0.3nm)、AuCu (0.5nm)/Cu (0.5nm)、AuCu (1nm)/Cu (0.5nm)、Ag (0.5nm)/Cu (0.5nm)、Cu (0.5nm)/Ag (0.5nm)、Ag (0.3nm)/Cu (0.3nm)/Ag (0.3nm)、Ag (0.3nm)/Cu (0.3nm)/Ag (0.3nm)/Cu (0.3nm)、Pt (0.5nm)/Cu (0.5nm)、Cu (0.5nm)/Pt (0.5nm)、Pt (0.5nm)/Cu (0.5nm)、Pt (0.5nm)、Pt (0.5nm)/Cu (0.5nm)/Pt (0.5nm)/Cu (0.5nm)、AuCu (0.5~1.5nm) などを用いた場合にも、同様な効果が得られた。

【0447】なお、第2の磁性層としてNiFeCrを用いた理由は以下の通りである。NiFeにCrを添加することによって、Msを低下させることなくρを向上させて、シャント分流の効果を低減させている。また、Cr添加による磁歪入が正側に上昇するのを抑えるため、NiとFeの比率は通常のゼロ磁歪組成である、Ni:Fe=81:19よりも少しNiリッチにすることが望ましい。Ms、ρ、磁歪の全てを満足する組成としては、Ni<sub>81</sub>Fe<sub>15</sub>Cr<sub>4</sub>の組成が好適である。これ以外に、Ni<sub>80</sub>Fe<sub>20</sub>、NiFeNb、NiFeRhなどを用いてもよい。

【実施例4】この実施例4では、Ta (5nm)/Au (1nm)/Cu (1nm)/IrMn (7nm)/CoFe (2.5nm)/Cu (2.5nm)/CoFe (4nm)/Cu (0.5nm)/Au (0.5nm)/Cu (0.5nm)/Ta (5nm) 構造のスピナル膜を、実施例1と同様にして作製した。

【0448】この実施例4は磁化固着層が非磁性中間層よりも下側にある、いわゆる反転構造のスピナル膜である。上層のCu/Au/Cu層はMR向上層であ

り、耐熱性、MR変化率を向上させている。下側のAu/Cu層はIrMnの下地膜になっていると同時に、IrMnの格子定数を安定に保つ働きをするMR向上層である。この膜のas-depoでのMR変化率は10%で、250℃×4Hのアニール後のMR変化率は9.5%であった。Cu/Au界面はAuCu合金を形成していた。

【0449】この実施例4の上側のTaは保護膜であり、Ta膜表面で反射を起こさせようとするものではない。この実施例4ではCu/Au/Cu層がMR向上層であるので、CoFe/Cu界面およびCu/Au界面 (もしくはAuCu合金層) で反射を起こさせるものである。このように、従来技術として示した(e)や(d)の構成とは明らかに異なるものである。さらに、極薄のCu層をCoFe/Au界面に挿入しているため、Auの非磁性中間層(Cu)への長期的な拡散を抑えると同時に、一旦フェルミ波長が短い層を介してAu層を配置しているため、反射効果を増大させることができる。

【0450】上側のMR向上層としてのAu (1nm)/Cu (1nm) に代えて、Au (0.5~3nm)/Cu (0.5~3nm)、Cu (0.5~3nm)/Au (0.5~3nm)/Cu (0.5nm)、AuCu (0.5~3nm)/Cu (0.5~3nm)、Cu (0.5~3nm)/AuCu (0.5~3nm)/Cu (0.5~3nm)、Ag (0.5~3nm)/Cu (0.5~3nm)、Cu (0.5~3nm)/Ag (0.5~3nm)/Cu (0.5~3nm)、Pt (0.5~3nm)/Cu (0.5~3nm)、Cu (0.5~3nm)/Pt (0.5~3nm)/Cu (0.5~3nm)、PtCu (0.5~3nm)/Cu (0.5~3nm)、Cu (0.5~3nm)/PtCu (0.5~3nm)/Cu (0.5~3nm) などを用いた場合にも、同様な効果が得られた。

【0451】また、他の材料については実施例1の場合の材料が用いられる。実施例4のフリー層の上層に積層されるMR向上層はシード効果は必要とされないため、膜厚は1nm程度に薄くしても構わない。ただし、厚いときのシャント分流増大の悪影響は実施例1のときと同様なため、5nm以下が望ましい。

【0452】反強磁性膜の下地にあるMR向上層は、反強磁性膜の格子間隔を適切な値にして、ピンCoFeと反強磁性膜の界面での格子不整合に起因する界面ミキシングを抑制するとともに、反強磁性膜自体の格子間隔を適切な値に制御することによって、ピン特性自体も向上させようとするものである。このときの具体的なMR向上層として、Al-Cu、Pt-Cu、Rh-Cu、Pd-Cu、Ir-Cu、Ag-Pt、Ag-Pd、Ag-Au、Au-Pt、Au-Pd、Au-Al、Ru-Rh、Ru-Ir、Ru-Pt、Ru-Cu、Ag-A

10

20

30

40

50

uの組み合わせの積層膜、合金膜などが例として挙げられる。

【0453】個々の反強磁性膜に適したMR向上層としては、Cu、Au、Ag、Pt、Rh、Ru、Pd、Al、Ti、Zr、Hfから選ばれる2つの元素の積層膜、合金膜が下地として効果を発揮する。ピン側だけの効果を狙うならば反転構造スピバルブ膜のフリー層の上層に積層されたMR向上層はなくても構わない。さらに、反強磁性膜の下地のMR向上層はピン膜構成が前述のようなシンセティックアンチフェロ構造であっても構わない。一例としてTa 5 nm/AuCu 2 nm/IrMn 7 nm/CoFe 3 nm/Ru 0.9 nm/CoFe 3 nm/Cu 3 nm/CoFe 1 nm/NiFe 5 nm/Ta 5 nmなどがある。

【0454】また、Ta保護膜に代えて、Ti、Zr、Cr、W、Hf、Nbなどを用いた場合についても同様であった。

【実施例5】この実施例5では、Ta (5 nm)/AuCu (2 nm)/IrMn (7 nm)/CoFe (2.5 nm)/AuCu (2.5 nm)/CoFe (4 nm) 20 /AuCu (2 nm)/Ta (5 nm) 構造の反転スピバルブ膜を、実施例1と同様にして作製した。ここで、下側のCoFe層(磁化固着層)と上側のCoFe層(感磁層)との間に配置されたAuCu層は、非磁性中間層であると同時に、感磁層の磁歪を制御するMR向上層である。

【0455】反転構造のスピバルブ膜では、Cuなどからなる非磁性中間層上に形成される感磁層のfcc-d (111)が小さくなり、磁歪が大きくなってしま 30 う。これに対して、この実施例5のように、非磁性中間層であると同時にMR向上層であるAuCu合金層上にCoFe感磁層を積層形成することによって、CoFe感磁層のfcc-d (111)スペーシングを適度な値に調整することができ、これにより感磁層の磁歪を低減することができる。

【0456】ところで、AuCu合金からなる非磁性中間層では、CoFe層との界面でのスピン依存散乱がCu単層の場合に比べて若干低下し、MR変化率が若干低下するおそれがある。このような点は非磁性中間層に例 40 えばCu (0.8 nm)/AuCu (0.8 nm)/Cu (0.8 nm) 積層膜などを使用することで解決することができる。

【0457】このような非磁性中間層であると同時にMR向上層の使用は、反転構造のスピバルブ膜に限らず、通常のスピバルブ膜やデュアルエレメントタイプのスピバルブ膜に対しても有効である。デュアルエレメントタイプのスピバルブ膜に非磁性中間層兼MR向上層を使用した例としては、Ta (5 nm)/AuCu (2 nm)/IrMn (7 nm)/CoFe 磁化固着層 (2.5 nm)/AuCu 非磁性中間層兼MR向上層 50

(2.5 nm)/CoFe感磁層 (3 nm)/Cu (2.5 nm)/CoFe磁化固着層 (2.5 nm)/IrMn (7 nm)/Ta (5 nm) 構造が挙げられる。通常のスピバルブ膜に非磁性中間層兼MR向上層を使用した例としては、Ta (5 nm)/AuCu (2 nm)/CoFe (4 nm)/Cu (0.8 nm)/AuCu (0.8 nm)/Cu (0.8 nm)/CoFe (2.5 nm)/IrMn (7 nm)/Ta (5 nm) 構造が挙げられる。

【0458】なお、反転構造のスピバルブ膜およびデュアルエレメントタイプのスピバルブ膜においてIrMnなどの反強磁性膜の下地として用いたAuCu層の効果などにより、CoFe感磁層のfcc-d (111)スペーシングが十分に制御されていれば、非磁性中間層には一般的なCu層などを使用することができる。

【0459】反転構造のスピバルブ膜およびデュアルエレメントタイプのスピバルブ膜の他の具体例としては、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (2.5 nm)/Ru (0.9 nm)/CoFe (3 nm)/Cu (3 nm)/CoFe (4 nm)/Ta (5 nm)、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (2.5 nm)/Cu (3 nm)/CoFe (4 nm)/Ta (5 nm)、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (2.5 nm)/Ru (0.9 nm)/CoFe (3 nm)/Cu (3 nm)/CoFe (2 nm)/NiFe (2 nm)/Ta (5 nm)、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (2.5 nm)/Cu (3 nm)/CoFe (2 nm)/NiFe (2 nm)/Ta (5 nm)、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (3 nm)/Cu (3 nm)/CoFe (1 nm)/NiFe (2 nm)/CoFe (1 nm)/Cu (3 nm)/CoFe (3 nm)/IrMn (7 nm)/Ta (5 nm)、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (3 nm)/Cu (3 nm)/CoFe (1 nm)/NiFe (2 nm)/CoFe (1 nm)/Cu (3 nm)/CoFe (3 nm)/IrMn (7 nm)/Ta (5 nm)、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (2.5 nm)/Ru (0.9 nm)/CoFe (3 nm)/Cu (3 nm)/CoFe (3 nm)/Ru (0.9 nm)/CoFe (2.5 nm)/IrMn (7 nm)/Ta (5 nm)、Ta (5 nm)/Au (1 nm)/Cu (1 nm)/IrMn (7 nm)/CoFe (2.5 nm)/Ru (0.9 nm)/CoFe (3 nm)/Cu (3 nm)/CoFe (1 nm)/NiFe (2 nm)/CoFe (1 nm)/Cu (3 nm) 50

m) / CoFe (3 nm) / Ru (0.9 nm) / CoFe (2.5 nm) / IrMn (7 nm) / Ta (5 nm) などが挙げられる。上記した Au / Cu 下地に代えて前述したような各種積層膜や合金層を用いることができる。

【0460】他の構造例としては、基板/Ta(5nm)/IrMn(7nm)/CoFe(2.5nm)/Ru(0.9nm)/CoFe(3nm)/Cu(3nm)/CoFe(2.5nm)/MR向上層/CoFe(2.5nm)/Cu(3nm)/CoFe(3nm)/Ru(0.9nm)/CoFe(2.5nm)/IrMn(7nm)/Ta(5nm)が挙げられる。この構造ではCoFe/MR向上層/CoFeがフ

10 リー層であり、強磁性的に結合している。

【0461】また、上述した各実施例では反強磁性膜にIrMnを使用した例に付いて説明したが、NiMn、PtMn、PdPtMn、RuRhMn、CrMn、NiOなど、種々の反強磁性材料を用いた場合においても、同様の効果を得ることができる。

【0462】さらに、上述のように磁化固着層に例えばCoFe/Ru/CoFe/IrMn、のような反強磁性カップリング(Ruを介したCoFe同士の反強磁性カップリング)などを用いたスピンバルブ膜においても

20 本発明は効果を発揮する。上記したような積層膜において、ある膜厚で反強磁性的な結合をする。

【0463】この場合、中間層を本発明のMR向上層とすることができる。例えばCoFe(2.5nm)/AuCu(1nm)/CoFe(2nm)/IrMn(反強磁性カップリング)、IrMn/CoFe(2nm)/AuCu(1nm)/CoFe(2nm)(反強磁性カップリング)などであり、またCoFe(1nm)/AuCu(0.5nm)/CoFe(2nm)/IrMn(7nm)のように、強磁性カップリングを適用する

30 こともできる。磁化固着層の中間に配置されたAuCu層などは、両側の磁性層を反強磁性的に結合させ、さらに鏡面反射効果をもたらすと同時にIrMnなどの格子を安定に保ち、スピンバルブ膜の耐熱性およびMR特性を向上させるものである。このような場合のMR向上層の膜厚は0.5~2nmの範囲とすることが好ましい。

(実施例6) 耐熱性の悪化の原因となる通常の結晶粒界はほとんどなく、完全単結晶ではないにしても、粒界が存在したとしても小傾角粒界のような耐熱性に優れた結晶構造を実現するための手段としても、Au/Cuなどの

【0464】ディフラクションパターンから、1μm以上の領域にわたって全てほぼ単一結晶構造の回折パターンが得られ、単結晶に近い構造を得られていることが分かった。Ta下地、保護膜を除く他は膜はfcc(111)配向している。回折パターンで中心点から半径Rの若干異なる点にスポットが見えた。これは、IrMnとCoFe/Cu/CoFeとではfcc(111)スペーシングの大きさが異なるからである。格子像を見ても非常にきれいなfcc(111)配向ができていることが確認できた。横方向での格子点が若干不連続になっているところがたまに見られた。回折パターンは全ての領域でほぼ単一のスポットしかでていないことから、上記した格子不連続は小傾角粒界のようなサブグレインバウンダリであると思われる。

【0465】このような単結晶に近い構造は、MR変化率、磁気特性の耐熱性に優れているだけでなく、電子の散乱の原因となる結晶粒界がほとんど存在しなくなるので、電子の平均自由行程も長くなり、MR変化率の絶対値を上昇させることにもなり、望ましい膜構造である。このような単結晶に近い構造を、熱酸化シリコン、アモルファスアルミナのようなアモルファス基板上で得る技術も本発明の特徴の一つである。ここでは熱酸化シリコン基板を用いたが、実際のヘッドで通常用いられているAlTiC基板上のアモルファスAlO<sub>1</sub>膜上や、その他の酸化物系アモルファス膜、窒化物系アモルファス膜、ダイヤモンドライクカーボン上でも構わない。

【0466】この実施例におけるAuの下地のTaは必ずしもTaでなくてもよいが、何らかの下地バッファ層は必要である。Auを直接熱酸化シリコン基板上に成膜しても、本発明のような単結晶に近い結晶構造の膜は得られない。Ta以外の材料としては、Ti、W、Zr、Mo、Hfやそれらを含む合金などを用いることができる。Ta/Au/Cu下地膜の場合には、TaとAuは合金を形成するため、Auが成膜されたときのAuのアイランド成長が妨げられ、二次成長しやすくなる。つまり、結晶粒としての凝集力よりも基板側との結合力が勝ることが膜成長により影響を及ぼす。

【0467】また、Ta/Au/Cuのような下地膜構成でも単結晶ライクな成長を促すのに効果がある。この場合のように、合金を形成する材料を積層膜にする場合もAuが成膜されるときにCu上にそのまま結晶粒を保ったまま成長するのではなく、下地との結合が大きくなって単結晶的な粒を形成する。このような構造は、Ta(5nm)/Cu(2nm)/CoFe(4nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)のように、単純なTa/Cu下地では得られない。

【0468】良好に実現する他の構造としては、実施例1のときと同様に、磁性層がCo系の膜の場合、Al-Cu、Pt-Cu、Rh-Cu、Pd-Cu、Ir-C

u、Ag-Pt、Ag-Pd、Ag-Au、Au-Pt、Au-Pd、Au-Alの積層膜または合金膜が挙げられる。積層膜の場合、繰り返し層数は2層以上であればいくつであっても構わない。また、磁性層がNi系の膜の場合、Au-Pt、Au-Pd、Au-Ag、Au-Al、Ag-Pt、Ag-Pd、Ru-Rh、Ru-Ir、Ru-Ptの組み合わせの積層膜、合金膜などが挙げられる。Co系のときと全く同様に、積層膜の層数は2層以上であれば何層であっても構わない。以上のような二つの金属の組み合わせのうち、固溶範囲が広いAu-Cu、Ag-Pt、Au-Pd、Au-Ag、Pt-Cuなどがある。また、固溶な組み合わせでなくても、Ru-Cu、Ag-Cuのような組み合わせの積層膜もある。

【0469】他の構造として、Ta/Cu/Au/Cu下地、Ta/Pt/Cu下地、Ta/Cu/Pt下地、Ta/Rh/Cu下地、Ta/Cu/Rh下地、Ta/Pd/Cu下地、Ta/Cu/Pd下地などが挙げられる。これらの材料でTaなどのバッファ層上の積層回数を増やしてもよい。また、Taの代わりにTi、W、Zr、Mo、Hfやそれらを含む合金などを用いることができる。fcc金属層の部分はシャント分流によるMR変化率の減少を防ぐため、抵抗を上げる元素を添加しない場合には、あまり厚くない方が好ましい。また逆に薄すぎるとfccのシード層としての効果が薄れてしまうため、あまり薄すぎないほうが好ましい。具体的には、Taなどの下地バッファ層を除いた下地シード層の膜厚は2~5nm程度が好ましい。ただし、添加元素などにより下地シード層の抵抗が上昇してシャント分流の心配が低減した場合には5nm以上としてもよい。

【0470】また、上記のような合金を形成するfcc金属の積層膜に代えて、fccを形成する前述の組み合わせの他に、それらにさらに添加元素を加えた合金が挙げられる。他には、Cuの代わりにNiとの合金で非磁性のfcc合金として、PtNi合金(Pt26at%よりもPtリッチが好ましい)、RhNi合金、PdNi合金(ほとんどの組成で磁性をもつため、第三元素の添加が好ましい)IrNi合金(Ir12at%よりもIrリッチが好ましい)などが挙げられる。これらの合金の場合にもTaバッファの代わりにTi、W、Zr、Mo、Hfやそれらを含む合金などを用いることができる。また、fcc合金膜の膜厚は上記の積層膜の場合と同様に2~5nm程度が好ましい。添加元素などにより抵抗が上昇した場合には5nm以上としてもよい。

【0471】上述したような構成の具体例としては、Ta(5nm)/Pt(1nm)/Cu(1nm)/CoFe(2~8nm)/Cu(3nm)/CoFe(2.5nm)/IrMn(7nm)/Ta(5nm)、Ta(5nm)/PtCu(2nm)/CoFe(2~8nm)/Cu(3nm)/CoFe(2.5nm)/Ir

Mn(7nm)/Ta(5nm)、Ta(5nm)/Au(1nm)/Cu(1nm)/IrMn(7nm)/CoFe(3nm)/Ru(1nm)/CoFe(3nm)/Cu(3nm)/CoFe(1nm)/NiFe(5nm)/Ta(5nm)、Ta(5nm)/Au(1nm)/Cu(1nm)/IrMn(7nm)/CoFe(2.5nm)/Cu(3nm)/CoFe(1nm)/NiFe(5nm)/Ta(5nm)、Ta(5nm)/Au(1nm)/Cu(1nm)/IrMn(7nm)/CoFe(3nm)/Ru(1nm)/CoFe(3nm)/Cu(3nm)/CoFe(4nm)/Ta(5nm)、Ta(5nm)/Au(1nm)/Cu(1nm)/IrMn(7nm)/CoFe(3nm)/Ru(1nm)/CoFe(3nm)/Cu(3nm)/CoFe(4nm)/Cu(3nm)/CoFe(3nm)/Ru(1nm)/CoFe(3nm)/IrMn(7nm)/Ta(5nm)、Ta(5nm)/AuCu(2nm)/IrMn(7nm)/CoFe(3nm)/Ru(1nm)/CoFe(3nm)/Cu(3nm)/CoFe(4nm)/Cu(3nm)/CoFe(3nm)/Ru(1nm)/CoFe(3nm)/IrMn(7nm)/Ta(5nm)などが挙げられる。

(実施例7) これまでのようなMR向上層は図49のような人工格子センサの場合にも適用できる。この場合、Coを含む膜、Niを含む膜のような磁性層71と、非磁性層72との積層層数はスピバルブ膜よりも多くなる。このときに最上層もしくは最下層の磁性層に接させてMR向上層73を配置させる。具体的な材料の考え方は実施例1のときなどと全く同様である。

【0472】以上、具体例を参照しつつ本発明の第1~第7の実施の形態について説明した。しかし、本発明は、これらの具体例に限定されるものではない。

【0473】例えば、図50~図52は、本発明のさらなる変型例を表す概念図である。

【0474】すなわち、図50は、ABS(エア・ベアリング・サーフェス)から見たスピバルブ素子部の断面を示すものであり、図51は、ギャップ膜やシールド膜を除いたスピバルブ素子の斜視図である。

【0475】アルチック基板10に下シールド11(NiFe、Co系アモルファス磁性合金、FeAlSi合金など、厚み:0.5~3μm、NiFeやFeAlSi合金では研磨により表面凹凸をシンセティックピン層の中間磁気結合層の厚み以下まで除去することが望ましい)、下ギャップ膜12(アルミナや窒化アルミなど)を形成し、その上にスピバルブ素子13を形成する。スピバルブ素子13はスピバルブ膜14と一対の縦バイアス膜15および一対の電極16から構成される。スピバルブ膜14は、実施例4に示したボトム型のSVから形成される。すなわち、Ta、Nb、Zr、Hf

等の非磁性下地層 141 (厚み: 1~10 nm)、必要に応じて Ru や NiFeCr などの第 2 の下地層 142 (厚み: 0.5~5 nm)、反強磁性層 143、強磁性層/磁気結合層/強磁性層からなるシンセテックピン層 144、非磁性スペーサ 145、フリー層 146、高電気伝導層 147、必要に応じて保護膜 148 (0.5~10 nm) から構成される。その上に上ギャップ層 17 (アルミナや窒化アルミなど)、上シールド 18 (NiFe、Co 系アモルファス磁性合金、FeAlSi 合金など、厚み: 0.5~3 μm) が形成される。図示していないが、さらにその上に記録部が形成される。スピンバルブ素子 13 は、スピンバルブ膜 14 のトラック幅端部を除去してそこに縦バイアス層 15 を形成したいわゆるアバットジャンクションタイプの素子構造からなる。縦バイアス層 15 には硬質磁性膜 (Cr、FeCo などの下地の上に形成した CoPt や CoPtCr など) 或いは強磁性層 151 と反強磁性膜 152 を順次積層して強磁性層をハード化したものが用いられる。先に反強磁性膜 152 を成膜して次に強磁性膜 151 を成膜しても良い。今後の狭トラックに対応して、トラック幅端での急峻な再生感度プロファイルを得るには、磁化自由層に対する縦バイアス強磁性層 (硬質磁性層または反強磁性膜で交換結合バイアスされた強磁性層) の磁気膜厚比、 $M_s \cdot t$  (縦バイアス) /  $M_s \cdot t$  (フリー) を 7 以下、望ましくは 5 以下に設定する。磁化自由層が 4.5 nm 厚以下 (磁気膜厚比: 5 nmT 以下) にまで薄くなると、 $M_s \cdot t$  (縦バイアス) /  $M_s \cdot t$  (フリー)  $\leq 5$  を満足するために、縦バイアス強磁性層も非常に薄くなる (磁気膜厚比で 25 nmT 以下)。

【0476】一般に、硬質磁性膜では膜厚が薄くなると高保磁力が得難くなるが、一方、強磁性膜/反強磁性膜タイプの縦バイアス層では強磁性膜 151 が薄くなるほど交換バイアス磁界が増大して固着が強固となるので、強磁性膜 151 / 反強磁性膜 152 タイプの縦バイアス層が望ましい。さらに、強磁性膜 151 / 反強磁性膜 152 の縦バイアス層では、強磁性層 151 の飽和磁化はフリー層の飽和磁化と概ね同様かそれ以上のものが完全な BHN (バルクハウゼンノイズ) 除去をなるべく小さな縦バイアス磁界で実現するのに好ましい。すなわち NiFe 合金でも良いが CoFe や Co 等のより飽和磁化が大きなもの望ましい。飽和磁化が小さな強磁性膜 151 を用いてその膜厚増大により漏洩磁界を強めて BHN 除去を実現すると、特に狭いトラック幅になると再生出力低下を引き起こす。

【0477】なお、図 50 ではスピンバルブ膜 14 を全てエッチング除去しないで反強磁性層 143 を残して縦バイアス層を形成した場合を示したが、下地層 141 までエッチング除去しても良い。反強磁性層 143 を残してその上に縦バイアス層 15 を形成すると縦バイアス層とスピンバルブ膜との電氣的接触が良くなる利点を有す

る。電極 16 が縦バイアス層 15 の間隔と概ね等しい一般的なアバットジャンクションでは、電極とスピンバルブ膜がダイレクトに面接触できないので反強磁性膜 143 を残すメリットが大きい。なお、反強磁性膜の上のピン層 144 は完全に除去してその上に縦バイアス層を形成することが望ましい。その理由は、後述するようにピン層 144 の磁化と縦バイアス層 15 の磁化の方向は概ね直交させることが必要なので、そうするとピン層 144 とその上の縦バイアス層 15 との磁気相互作用により縦バイアス層の磁化が不安定になるためである。或いは、高導電層 147 まではエッチング除去してフリー層を完全に除去すること無く、その上縦バイアス層を形成しても良い。

【0478】また、結晶性改善のために、或いは反強磁性層 143 と縦バイアス層 15 との磁気結合を弱めるために、強磁性層 151 の下に下地層 142 と同様な極薄い下地層 153 を設けても良い。強磁性層と強磁性層の間には、僅かな厚みの非磁性層が存在しても磁気結合が発生し易いが、反強磁性層と強磁性層の間では僅かでも非磁性層が存在するともやは磁気結合を生じない。縦バイアス層からのバイアス磁界を有効にフリー層に加えるために、下地層 153 の厚みは 10 nm 以下が望ましい。硬質磁性膜を用いる場合にも同様にフリー層と硬質磁性膜の飽和磁化を揃えることが望ましいが、CoFe などの高飽和磁化フリー層に匹敵する高飽和磁化硬質磁性膜を作製することは通常困難である。

【0479】そこで、硬質磁性膜の下地に FeCo のような CoFe に匹敵する高飽和磁化の下地を用いてフリー層との飽和磁化のバランスを保つことが、小さな縦バイアス磁界で BHN を除去するのに適する。反強磁性膜 152 にはスピンバルブ膜に用いたものと同様な反強磁性膜材料を用いることが出来る。

【0480】しかし、スピンバルブの反強磁性層と縦バイアス層の反強磁性膜 152 の交換バイアス方向は直交させる必要がある (スピンバルブ膜の反強磁性層の交換バイアス方向は素子幅 (ハイト) 方向、縦バイアス層の反強磁性膜 152 の交換バイアス方向はトラック幅方向)。

【0481】そこで、例えば、両者の反強磁性膜のプロッキング温度  $T_b$  を変えて、最初に高  $T_b$  側の反強磁性膜の交換バイアス方向を熱処理により規定して、それより低い温度で尚且つ最初に  $T_b$  を規定した反強磁性膜の交換バイアスにより固着された強磁性膜の磁化方向が安定な温度近傍にもう一方の反強磁性膜の  $T_b$  を設定することにより、両反強磁性膜の交換バイアスの直交化が実現できる。反強磁性層 152 の交換バイアス付与には、磁界中成膜 (IrMn、RhMn などを用いる) や記録部形成における 200~250℃ のレジストキュア熱処理工程 (PtMn、PdPtMn、IrMn などを用いる) を利用することが望ましい。スピンバルブ膜の反

強磁性層にはそれよりTbが高い反強磁性膜(IrMn, PtMn, PdPtMn等)を用いると、レジストキュアー熱処理工程にてスピバルブ膜のピン層磁化の方向を乱すことなく反強磁性膜152の交換バイアス方向をトラック幅方向に規定できる。

【0482】従来の単層ピン層スピバルブでは反強磁性膜152の交換バイアス付与熱処理をかなり下げないとピン層固着の交換バイアス磁界方向が乱れてしまい実用困難であったが、ブロッキング温度以下でピン磁化の耐熱性が急激に安定するシンセティックピン層の性質を利用すると、両反強磁性膜間の数十℃程度の僅かなブロッキング温度の差でも良好な縦バイアスとピン層磁化の直交化が可能になる。なお、反強磁性層152に規則化系反強磁性膜PtMnやPdPtMnを用いる場合は、レジストキュアー温度(200~250℃)で規則化を生じる反強磁性膜が好ましい。

【0483】電極16の間隔LDは、縦バイアス層の間隔HMDよりも狭いことが、再生素子抵抗を下げてESDに強いヘッドを実現するために好ましい。LDは再生トラックを概ね規定するので、本発明が狙う高密度記録(10Gbps以上)では0.1~0.7μmのサブミクロン幅となる。一方、HMDはLDよりもおよそ0.3~1μm広めることにより、狭トラック幅でもハード膜磁界の影響が少なく急峻なトラック幅方向感度プロファイルが実現でき、高感度な再生が可能になる。さらに、HD(素子幅)>LD且つHMD>HDとすることにより、電極間のスピバルブ素子抵抗が低減できて、合わせてスピバルブ感磁部の形状がトラック幅方向に長い長方形となるのでバルクハウゼンノイズ抑制が容易となる。具体的には、素子幅HDは0.4μm程度が耐ESDを考えると望ましく、電極間隔を0.4μm以下に狭めた狭トラック幅再生ではハード膜間隔HMDを0.8μm程度に広げることが望ましい。

【0484】図50においてフリー層の膜厚中心から上シールド表面までの間隔をgf、下シールド表面までの間隔をgpとすると、フリー層に加わる電流磁界Hcuを弱めるためには、gf<gpとすることが望ましい。これは、フリー層が下シールドよりも上シールドに近いので、フリー層は下シールドからの磁界の影響を強く受け、なお且つセンス電流の流れる中心が非磁性スペーサ145側に存在するのでフリー層にはセンス電流磁界方向と逆方向に下シールドからの磁界(センス電流によりシールドが磁化されるために発生)が加わるためである(図50参照)。センス電流磁界が弱まると、より大きなセンス電流が投入でき、より高い再生出力および良好なBP、すなわち上下再生波形の非対称性が小さな再生波形が得られる。具体的には、gpは35~80nm、gfは25~50nmとしてgf<gpとすると、ギャップの絶縁性も保ってなお且つトータル再生ギャップ長も60~130nmの著しい狭ギャップが実現でき

る。

【0485】図52は、図1や図5などに例示したトップ型のスピバルブ膜に適するヘッドの一実施例を示す概念図である。図50と異なるところは、縦バイアス層15はスピバルブ膜を全部エッチング除去した後に下ギャップ膜12上に形成される点である。さらに、フリー層膜厚中心と下シールド表面との間隔gfが上シールド表面との間隔gpよりも小さいことが望ましい。これは、フリー層が上シールドよりも下シールドに近いのでフリー層は下シールドからの磁界の影響を強く受け、なお且つセンス電流の流れる中心が非磁性スペーサ145側に存在するのでフリー層にはセンス電流磁界方向と逆方向に下シールドからの磁界(センス電流によりシールドが磁化されるために発生)が加わるためである。センス電流磁界が弱まると、より大きなセンス電流が投入でき、より高い再生出力および良好なBP、すなわち上下再生波形の非対称性が小さな再生波形が得られる。具体的には、gpは35~80nm、gfは25~50nmとしてgf<gpとすると、ギャップの絶縁性も保ってなお且つトータル再生ギャップ長も60~130nmの著しい狭ギャップが実現できる。

【0486】また、本発明による磁気抵抗効果素子の膜構成は、種々の分析手法により同定可能である。

【0487】図53は、本発明による磁気抵抗効果素子を用いた磁気ヘッドの膜断面におけるナノEDX分析の結果を示すグラフ図である。例えば、断面TEM(transmission electron microscopy)観察用のサンプルを作製し、その膜断面に対して直径約1nmのビームを用いたナノEDXにより、磁気抵抗効果素子を構成している材料、および膜厚を特定することができる。測定限界および熱処理による界面拡散の影響を適宜考慮することによって、膜構成を概ね再現することができる。特に、図53からも分かるように、フリー層とスペーサCuの界面、およびフリー層と非磁性高導電層のCuとの界面は比較的シャープであり膜厚を特定しやすい。

【0488】膜厚決定の定義としては、所望の膜を構成している主元素の材料のピークの半値幅を膜厚とすることができる。例えば、スペーサCuと下地非磁性高導電層のCuについてはシャープなピークなため膜厚を決定しやすいので、フリー層の膜厚は上下のCu層に挟まれた領域をフリー層膜厚とする。図53の例では、スペーサCuは2.4nm、非磁性高導電層は2nmと求まり、その両者のCuに挟まれたフリー層のトータル膜厚は4.1nmとすることができる。このフリー層膜厚は所望のフリー層膜厚3.7nmをほぼ再現した値である。このような分析手法によりスピバルブ膜の膜構成は概ねわかり、スペーサ層、非磁性高導電層、フリー層については極薄の膜厚についても比較的正確に測定することができる。

【0489】

【発明の効果】本発明は、以上説明した形態で実施され、以下に説明する効果を奏する。

【0490】まず、本発明によれば、前述した第1の実施の形態を適用することによって、従来スピバルブ膜を単純にフリー層を薄膜化するだけでは達成できなかった、良好なバイアスポイント、および高MR、高 $\Delta R_s$ を実現し、かつ製造ばらつきに対しても広いマージンをもつ、次世代スピバルブ膜が得られる。

【0491】また、本発明によれば、前述した第2乃至第6の実施の形態を適用することによって、今後ハードディスクドライブの高密度記録化に伴って、ドライブにおける動作時に磁気ヘッドの温度が例えば200℃前後であっても、磁化固着層が安定であり、また静電放電電流が磁気抵抗効果ヘッドのGMR素子に流入しても磁化固着層の磁化固着が乱されることがなく安定である。またセンス電流の分流が小さいためGMR素子として高い抵抗変化率が保たれて再生感度が確保されるので、より一層の高密度の記録が可能になり、高い再生出力を得ることができる。

【0492】さらに、本発明によれば、前述した第7の実施の形態を適用することによって、MR向上層により初期プロセスアニール劣化を抑制することができると同時に、鏡面反射効果によりMR変化率の向上を図ることができる。また、フリー層が薄い場合においては、MR向上層とフリー層の界面を安定な界面にすることができるので、熱処理を行った後でも、その界面において電子の透過率を高いまま維持でき、高いMR変化率を保つことができる。さらに、例えばC<sub>60</sub>系磁性材料からなる感磁層をMR向上層により低磁歪化したり、また結晶微細構造を制御することができる。これらによって、高出力、低ノイズ、高耐熱性の磁気抵抗効果素子を提供することが可能となる。

【0493】以上詳述したように、本発明によれば、高性能且つ高信頼性を有する磁気抵抗効果素子を実現することが可能となり産業上のメリットは多大である。

#### 【図面の簡単な説明】

【図1】本発明の磁気抵抗効果素子の断面構成を表す概念図である。

【図2】本発明のスピバルブ膜においてえられるトランスファーカーブの概略図である。

【図3】フリー層に接しているスペーサとは反対側の高導電層Cuの膜厚に対するフリー層に加わる電流磁界H<sub>cu</sub>の関係を表すグラフ図である。

【図4】アシメトリが-10%~+10%、つまり、バイアスポイント30%~50%を実現するためのシンセティックAFのピン層厚と、非磁性高導電層厚との具体的な範囲を表したグラフ図である。

【図5】本発明の一実施例の磁気抵抗効果素子の具体的な膜構成を示す概念図である。

【図6】本発明の一実施例にかかるスピバルブ膜構成

を表す概念図である。

【図7】従来の磁気抵抗効果素子が有する2つの問題を説明するための概念図である。

【図8】計算上のバイアスポイント値とヘッドの再生信号波形の関係を示すグラフ図である。

【図9】各磁界の関係を表す説明図である。

【図10】各層を流れる電流分流I<sub>1</sub>~I<sub>3</sub>を表す概念図である。

【図11】比較例におけるバイアスポイントの状態を表す概念図である。

【図12】トランスファーカーブでみたときのH<sub>in</sub>、H<sub>pin</sub>、H<sub>cu</sub>の大きさとバイアスポイントとの関係を表した概念図である。

【図13】比較例におけるバイアスポイントの決定要素の関係を表す概念図である。

【図14】比較例におけるバイアスポイントの決定要素の関係を表す概念図である。

【図15】各比較例のスピバルブ膜と本発明によるスピバルブ膜のバイアスポイントのフリー層厚依存性を比較しつつ表したグラフ図である。

【図16】比較例1~4の構造において、フリー層のM<sub>s</sub>tだけを小さくした時にMR変化率がどのように変化するかを表したグラフ図である。

【図17】本発明の磁気抵抗効果ヘッドの一実施形態を示す図である。

【図18】外部磁界に対するスピバルブ膜の抵抗値の変化と、交換バイアス磁界H<sub>ex</sub>\*を示す模式図である。

【図19】模擬バイアス磁界を与えた場合の経過時間と磁化固着層の磁化の動いた角度との関係を示す図。

【図20】反強磁性層の最密面からの回折線ピークのロッキングカーブ半値幅を示す図。

【図21】磁気結合層に、Ruを用いた場合の熱処理後のRu厚と反強磁性結合の低下度合の関係を残留磁化比M<sub>r</sub>/M<sub>s</sub>によって示した図である。

【図22】スピバルブ膜の磁界に対する抵抗値の変化を示す図である。

【図23】強磁性層Aと強磁性層Bの膜厚を異ならせることによって、磁界による抵抗変化が相違することを示す図である。

【図24】スピバルブ素子にヒューマンボディモデルによる模擬のESD電圧を与えた後の抵抗と出力を示す図である。

【図25】スピバルブ素子にヒューマンボディモデルによる模擬のESD電圧を与えた後の抵抗と出力を示す図である。

【図26】スピバルブ素子の漏洩磁界を示す図である。

【図27】本発明の磁気抵抗効果ヘッドの他の一実施形態を示す図である。

【図28】本発明の磁気抵抗効果ヘッドのさらに他の一

実施形態を示す図である。

【図 29】本発明の磁気抵抗効果ヘッドのさらに他の一実施形態を示す図である。

【図 30】本発明の磁気抵抗効果ヘッドのさらに他の一実施形態を示す図である。

【図 31】本発明の磁気抵抗効果ヘッドのさらに他の一実施形態を示す図である。

【図 32】本発明の磁気抵抗効果素子の第 1 の実施形態の要部構造を示す断面図である。

【図 33】図 32 に示す磁気抵抗効果素子の變形例を示す断面図である。 10

【図 34】図 32 に示す磁気抵抗効果素子の他の變形例を示す断面図である。

【図 35】従来のスピバルブ膜の熱プロセスによる MR 変化率の低下モデルを示す図である。

【図 36】金属膜／金属膜界面で鏡面反射効果が得られることを説明するための図である。

【図 37】反射膜のフェルミ波長およびそれと接する GMR 膜のフェルミ波長の比と臨界角度  $\theta$ 。との関係の一例を示す図である。 20

【図 38】Au (Ag) / Cu 界面で鏡面反射を起こす臨界角度  $\theta$ 。をフェルミ波長から算出した結果を示す図である。

【図 39】図 32 に示す磁気抵抗効果素子のさらに他の變形例を示す断面図である。

【図 40】図 39 に示す磁気抵抗効果素子の變形例を示す断面図である。

【図 41】本発明の磁気抵抗効果素子の第 2 の実施形態の要部構造を示す断面図である。

【図 42】図 41 に示す磁気抵抗効果素子の變形例を示す断面図である。 30

【図 43】本発明の磁気抵抗効果素子の第 3 の実施形態の要部構造を示す断面図である。

【図 44】本発明の磁気抵抗効果素子を適用した録再分離型磁気ヘッドの第 1 の実施形態の構造を示す断面図である。

【図 45】本発明の磁気抵抗効果素子を適用した録再分離型磁気ヘッドの第 2 の実施形態の構造を示す断面図である。

【図 46】本発明の録再分離型磁気ヘッドを適用した磁気ヘッドアセンブリの一実施形態の構造を示す斜視図である。 40

【図 47】本発明の録再分離型磁気ヘッドを適用した磁気ディスク装置の一実施形態の構造を示す斜視図である。

【図 48】本発明の実施例 1 で作製したスピバルブ膜の XRD パターンを示す図である。

【図 49】本発明の磁気抵抗効果素子を人工格子膜に適用した実施例の要部構造を示す断面図である。

【図 50】ABS (エア・ベアリング・サーフェス) から見たスピバルブ素子部の断面を示す概念図である。

【図 51】ギャップ膜やシールド膜を除いたスピバルブ素子の斜視図である。

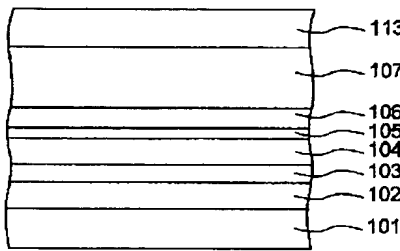
【図 52】図 1 や図 5 などに例示したトップ型のスピバルブ膜に適するヘッドの一実施例を示す概念図である。

【図 53】本発明による磁気抵抗効果素子を用いた磁気ヘッドの膜断面におけるナノ EDX 分析の結果を示すグラフ図である。

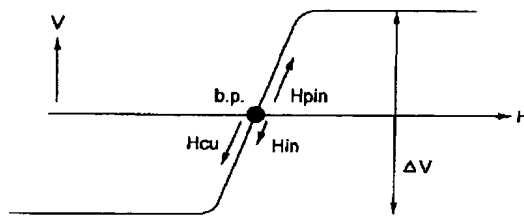
#### 【符号の説明】

- 1 感磁層
- 2 磁化固着層
- 3 非磁性中間層
- 4 MR 向上層
- 4 a, 4 b 金属膜
- 4 c 合金層
- 5 非磁性下地層
- 6 反強磁性層
- 7 保護層
- 8 スピバルブ膜
- 10 基板
- 11, 18 シールド
- 12, 17 ギャップ膜
- 13 スピバルブ素子
- 14 スピバルブ膜
- 15 縦バイアス膜
- 16 電極
- 141, 142 非磁性下地層
- 143 反強磁性層
- 144 磁化固着層
- 145 中間層
- 146 磁化自由層
- 147 保護膜
- 151 強磁性膜
- 152 反強磁性膜
- 153 下地層
- 1441 強磁性層 B
- 1442 磁気結合層
- 1443 強磁性層 A

【図1】

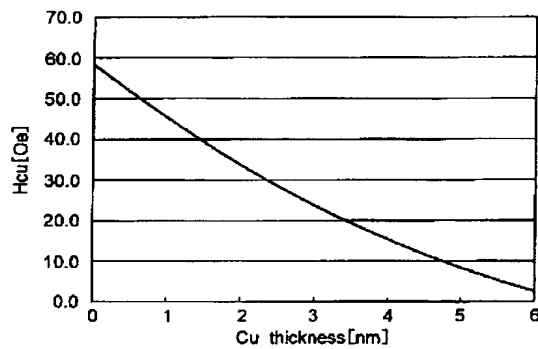


【図2】

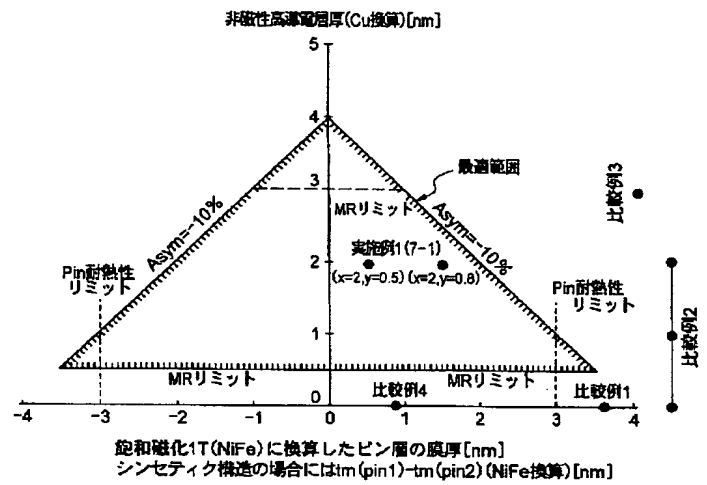


【図4】

【図3】

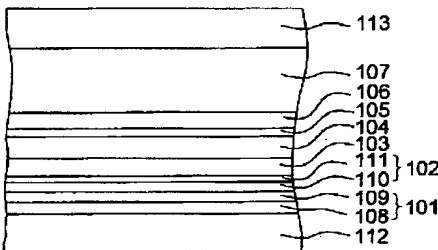


【図5】



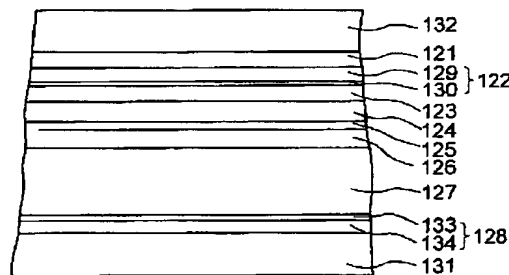
飽和磁化1T (NiFe) に換算したピン層の膜厚 [nm]  
シンセティック構造の場合には  $tm(pin1) - tm(pin2)$  (NiFe換算) [nm]

本発明による非磁性高導層の膜厚とピン層膜厚の範囲



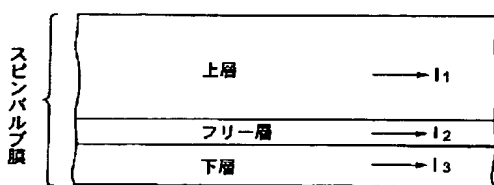
本発明(トップタイプでの実施例)

【図6】



本発明(ボトムタイプでの実施例)

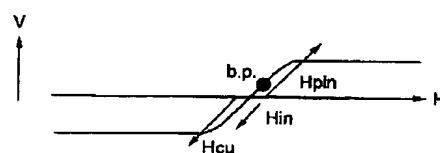
【図10】



センス電流:  $I_3 = I_1 + I_2 + I_3$  [mA]

スピンバルブ膜の電流分流通式図

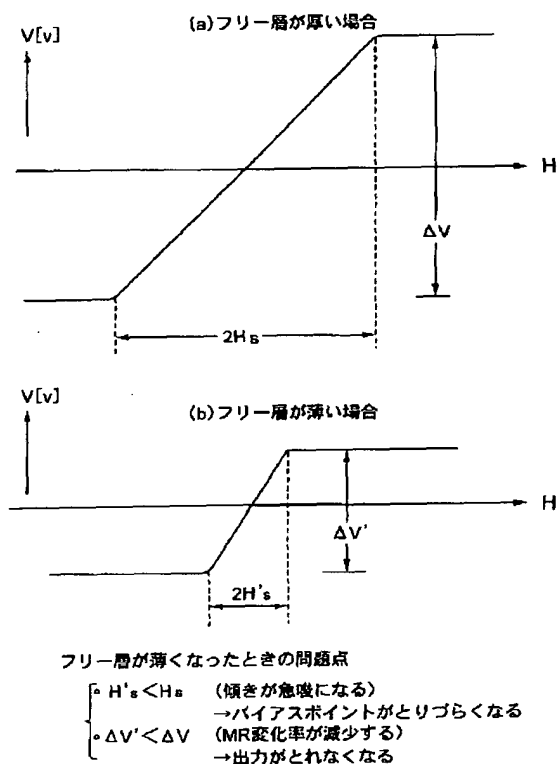
【図11】



比較例1 (Spin-Filterなしノーマルピン) のバイアスポイント

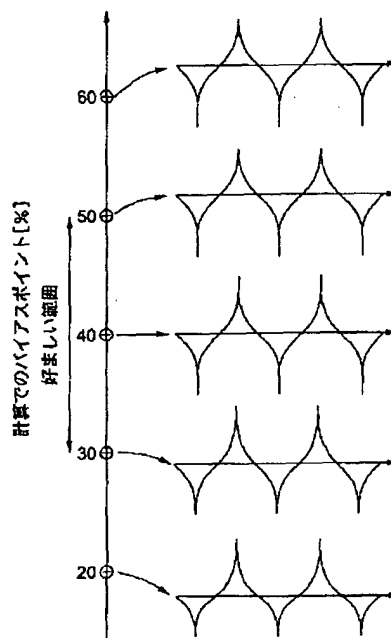
- 大きいHpinを大きいHcurrentでジャストバイアスにもってくるのは制御性が悪い(ハイト依存症が大きい)
- Spin-Filter効果を用いていない為、出力が低下する

【図7】

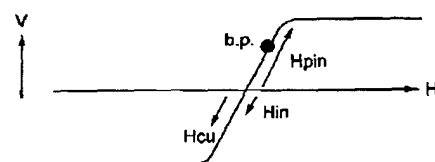


【図8】

バイアスポイントとヘッド再生出力波形との関係



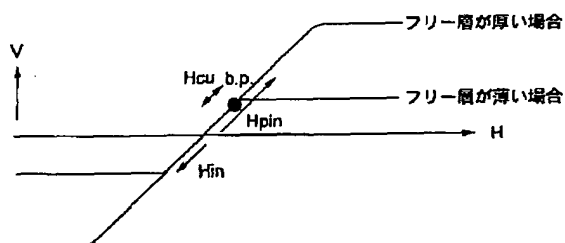
【図12】



比較例2 (Spin-Filterあり×ノーマルピン) のバイアスポイント

(  $H_{pin}$  が大きく  $H_{cu}$  は小さい為 b.p. は 50% よりもかなり大きくなってしまふ。 )

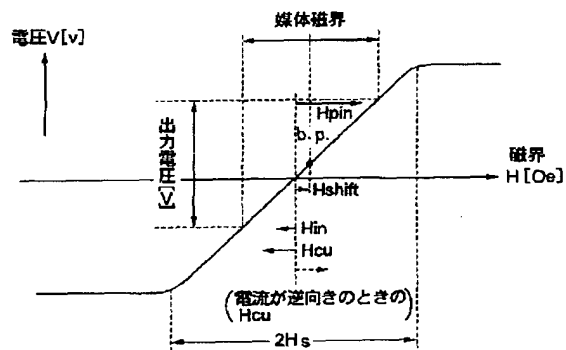
【図13】



比較例3のバイアスポイント

- フリー層が厚い場合には、 $H_{cu}$  だけの低減でバイアスポイントが安定する。
- フリー層が薄くなると、 $H_{pin}$  の影響が大きく、b.p. がはずれる。さらにMRも劣化する。

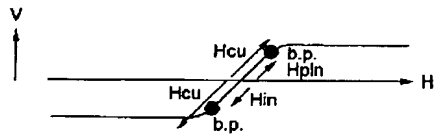
【図9】



$$H_{shift} = -H_{in} + H_{pin} - H_{cu} \quad (\text{または} +H_{cu})$$

トランスファークラップ上に示したバイアスポイント(b.d.)の概念図

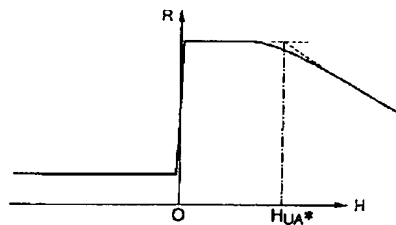
【図14】



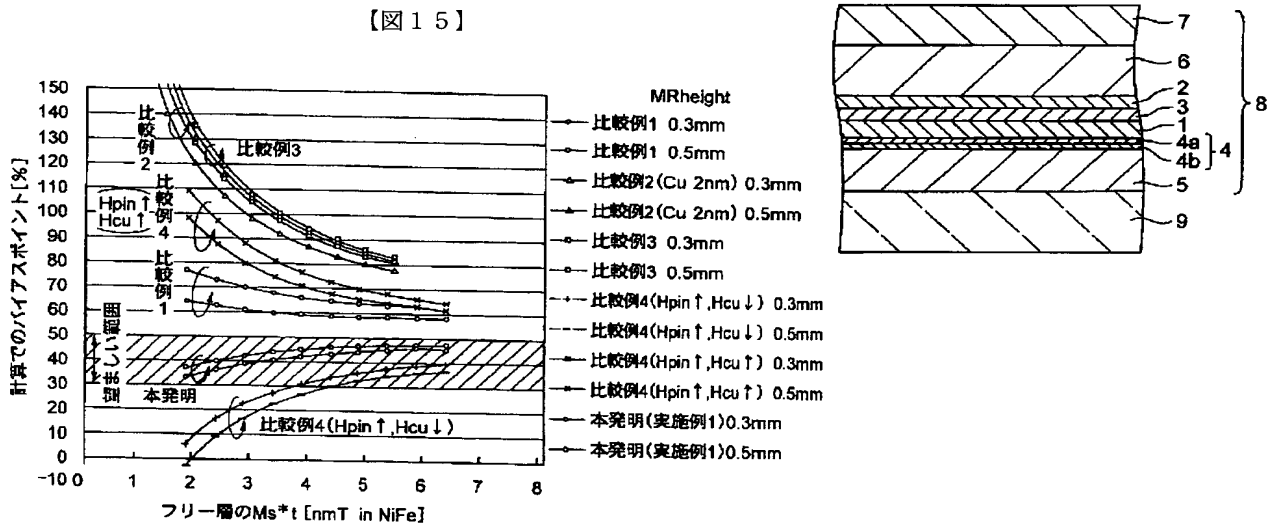
比較例4 (Spin-Filterなし×シンセティックAF)のバイアスポイント

- $H_{in}, H_{pin}$  が小さく  $H_{in} + H_{pin}$  がほぼ50%に近いところで  $H_{cument}$  が大きいと、電流をどちら向きに流してもジャストバイアスが得られなくなってしまう
- スピンフィルターがない為MRが減少する

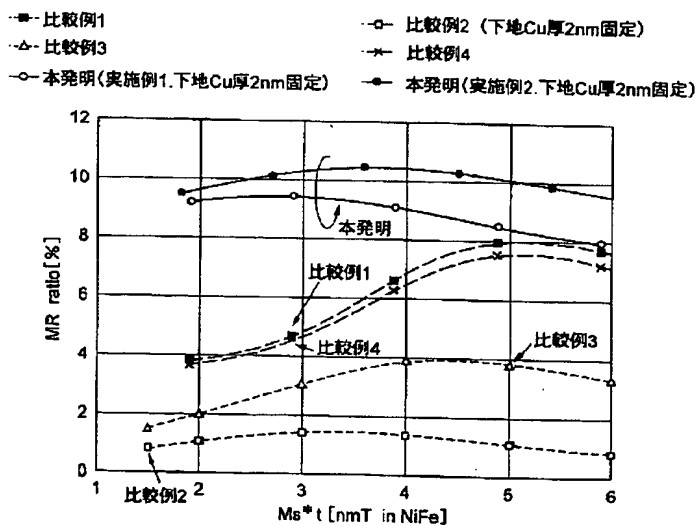
【図18】



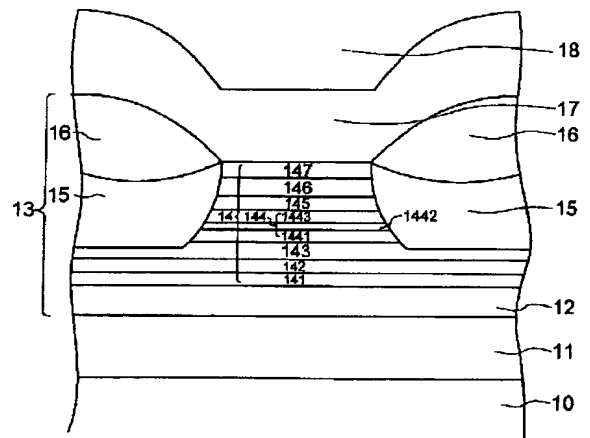
【図32】



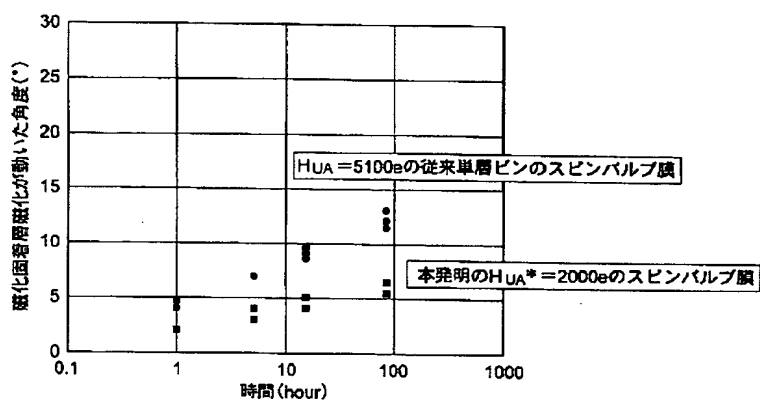
【図16】



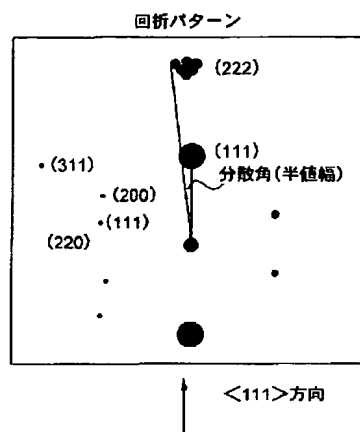
【図17】



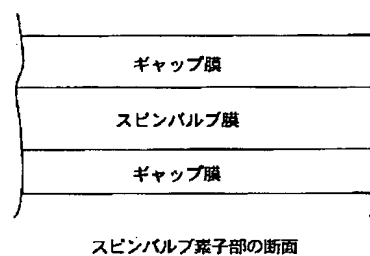
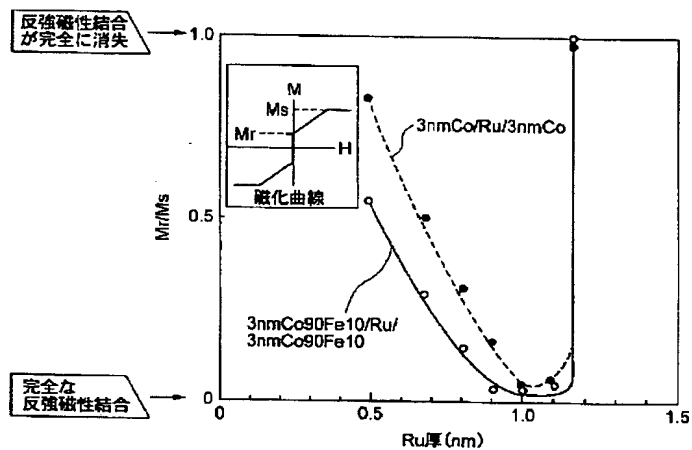
【図 19】



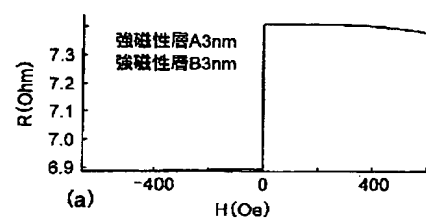
【図 20】



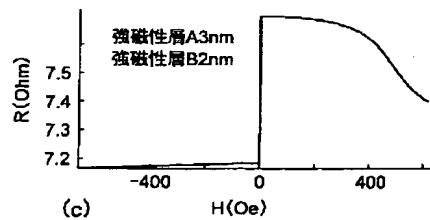
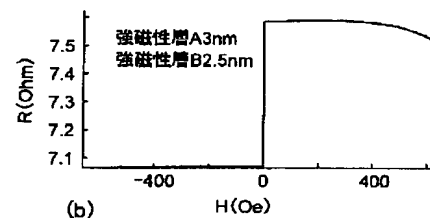
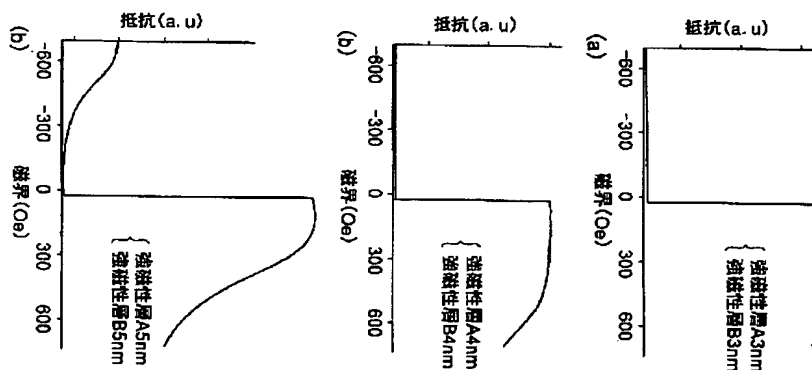
【図 21】



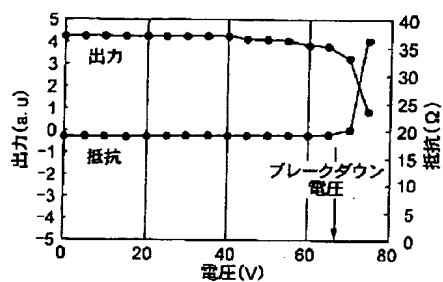
【図 23】



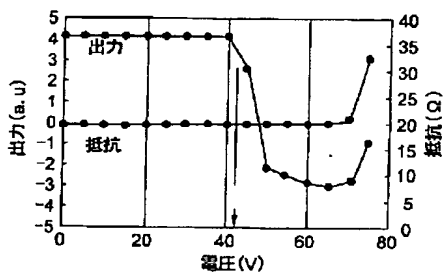
【図 22】



【図24】



(a) +方向のESD電流

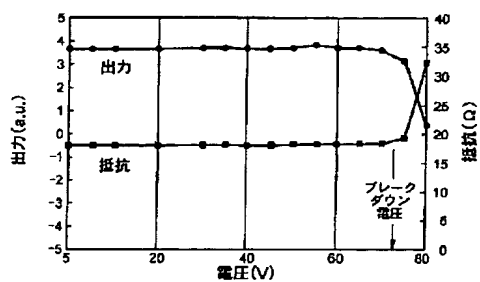


(b) -方向のESD電流

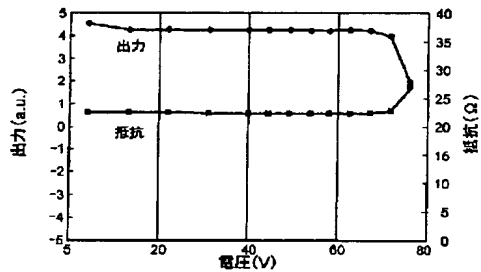
SV膜構成:

5nmTa/1.8nmNiFe/4nmCoFe/3nmCu  
 3nmCoFe/0.9nmRu/3nmCoFe/10nmIrMn/5nm  
 {電圧:ヒューマンボディモデルによるESD電圧  
 ESD電流: +方向はESD電流磁界が強磁性層Bの磁化と同方向に加わる方向  
 強磁性層Aの強磁性層Bの磁気膜厚が等しい場合}

【図25】



(c) +方向のESD電流

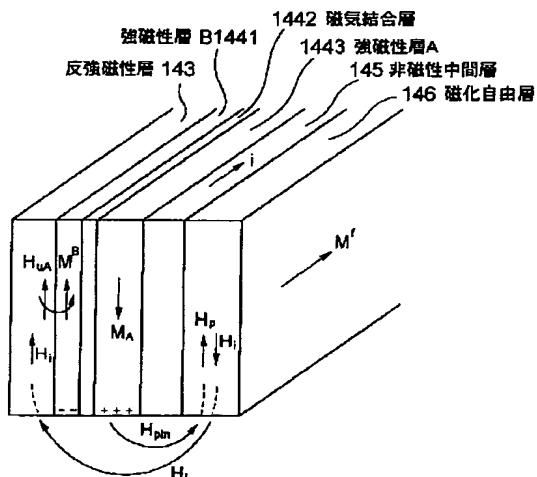


(d) -方向のESD電流

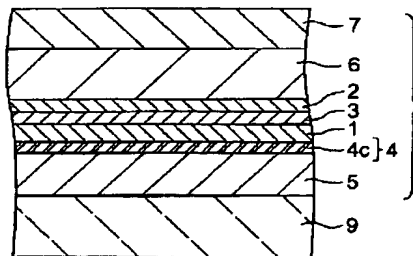
SV膜構成:

5nmTa/1.8nmNiFe/4nmCoFe/3nmCu/  
 3nmCoFe/0.9nmRu/2.5nmCoFe/10nmIrMn/5nmTa  
 {電圧:ヒューマンボディモデルによるESD電圧  
 ESD電流: +方向はESD電流磁界が強磁性層Bの磁化と同方向に加わる方向  
 強磁性層Aの磁気膜厚 > 強磁性層Bの磁気膜厚の場合}

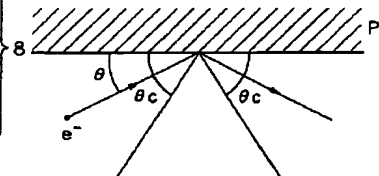
【図26】



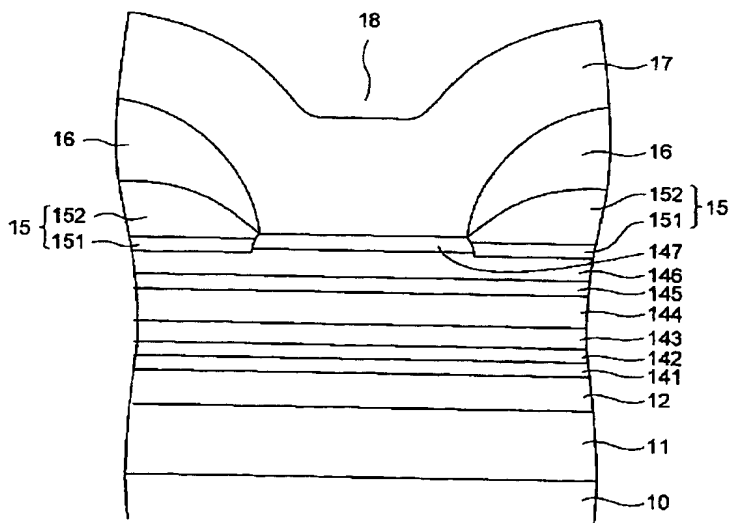
【図33】



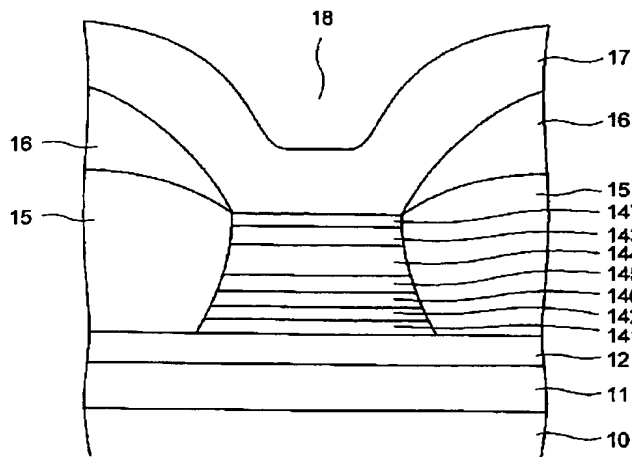
【図36】



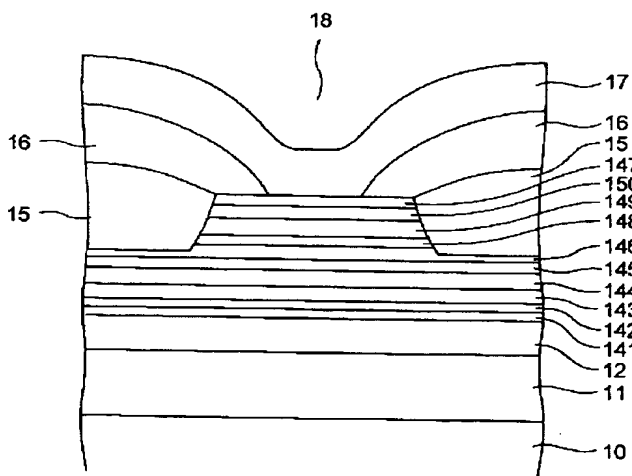
【図27】



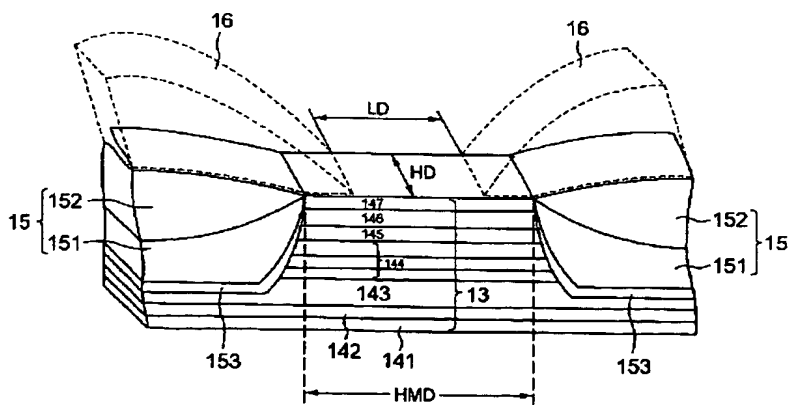
【図 28】



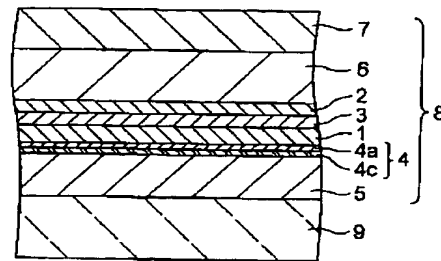
【図 29】



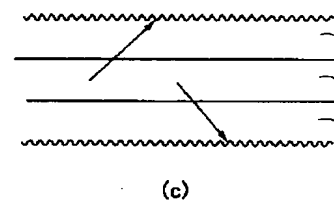
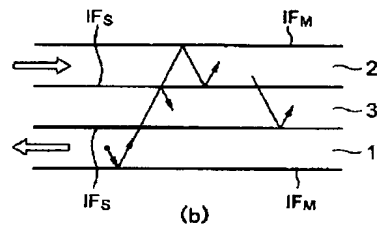
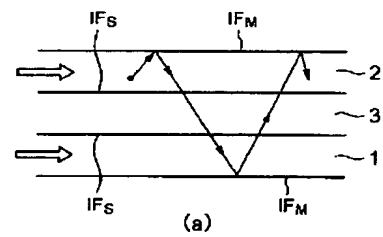
【図 30】



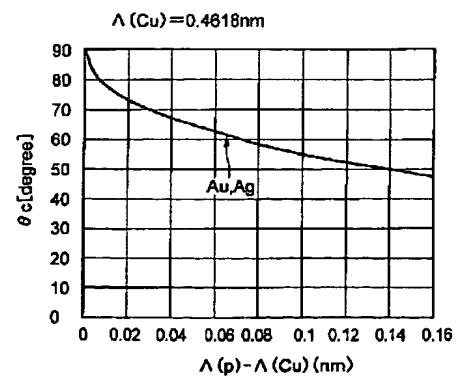
【図 34】



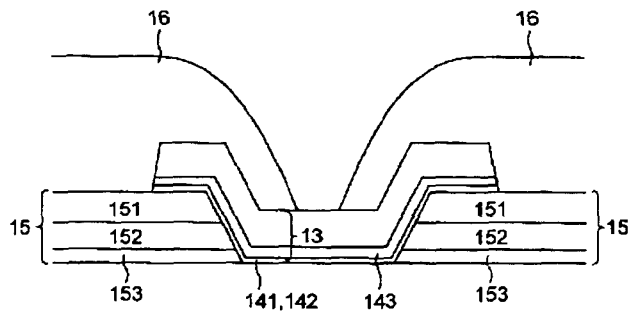
【図 35】



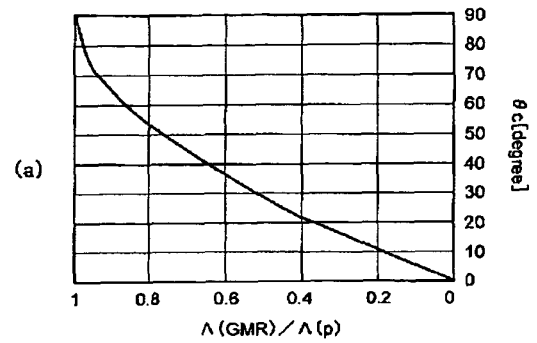
【図 38】



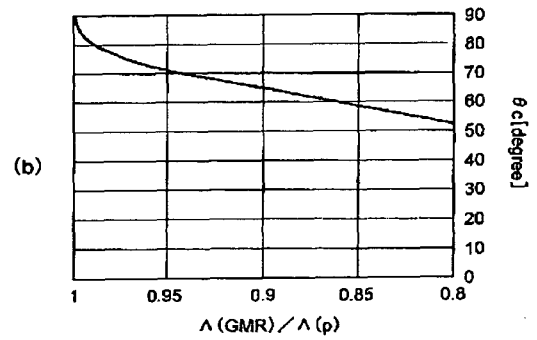
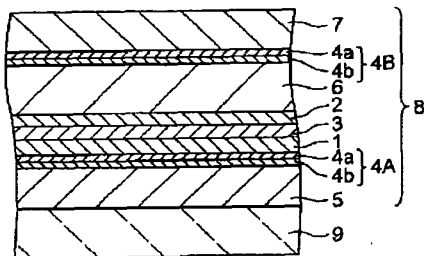
【図 31】



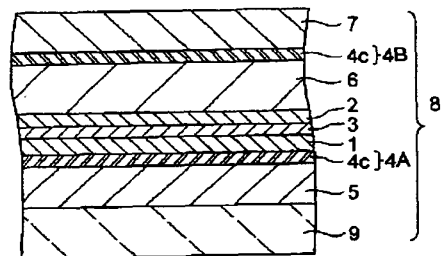
【図 37】



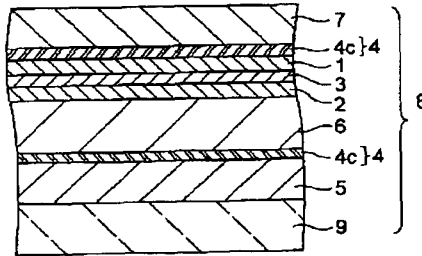
【図 39】



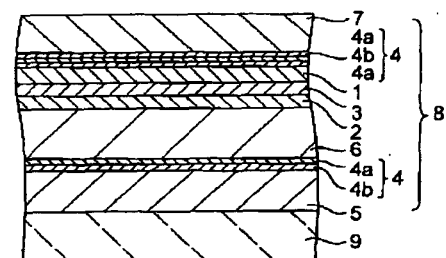
【図 40】



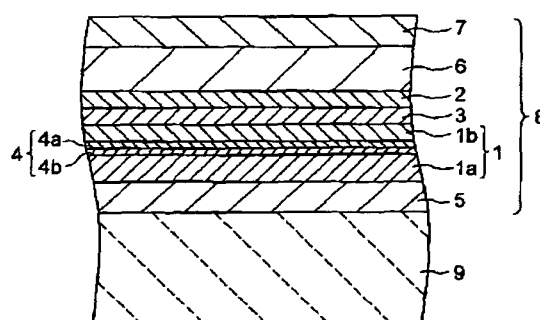
【図 41】



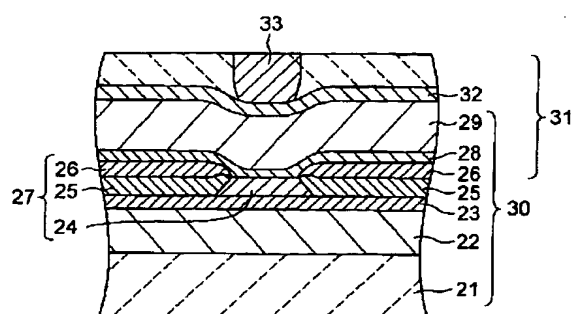
【図 42】



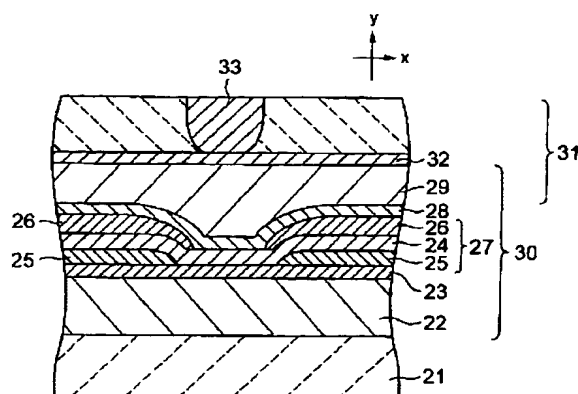
【図 43】



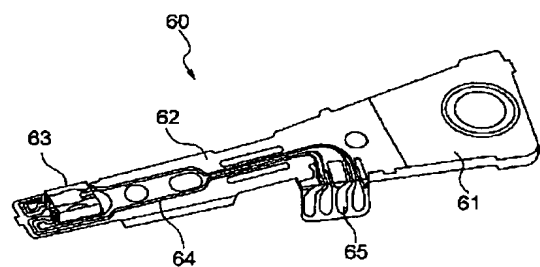
【図44】



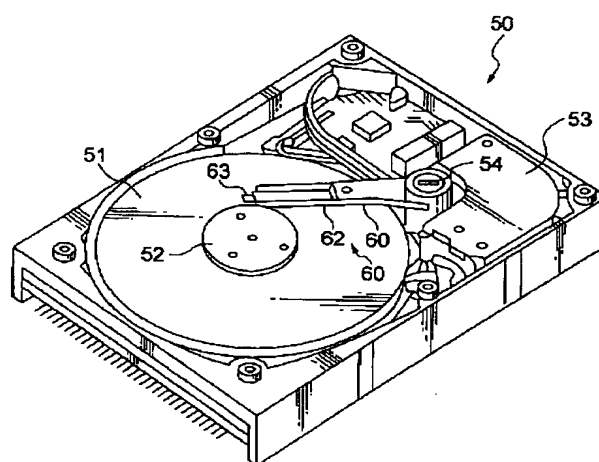
【図45】



【図46】

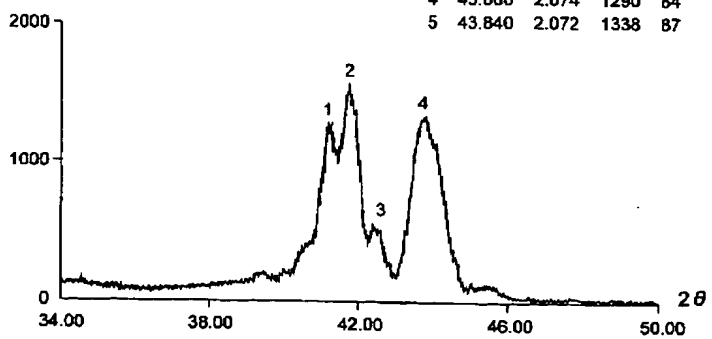


【図47】

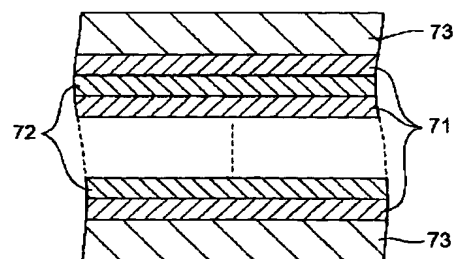


【図48】

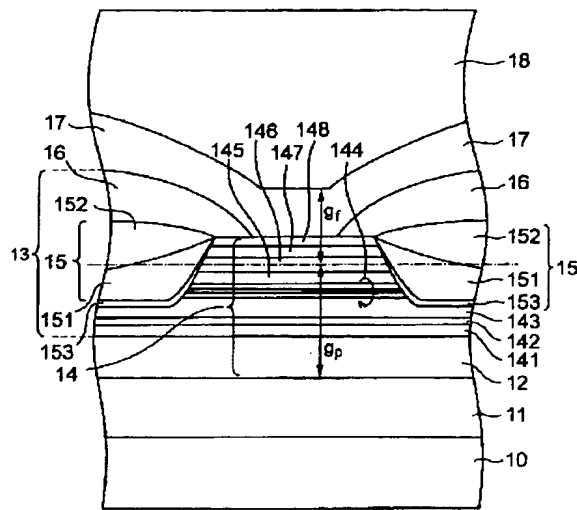
カウント 2θ-34.000 カウント=100



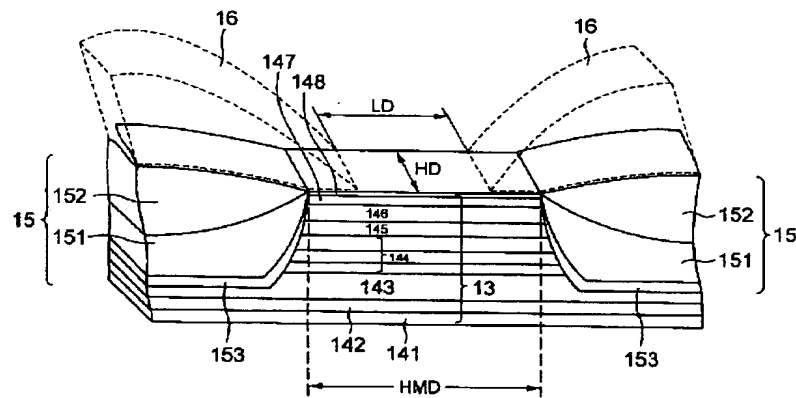
【図49】



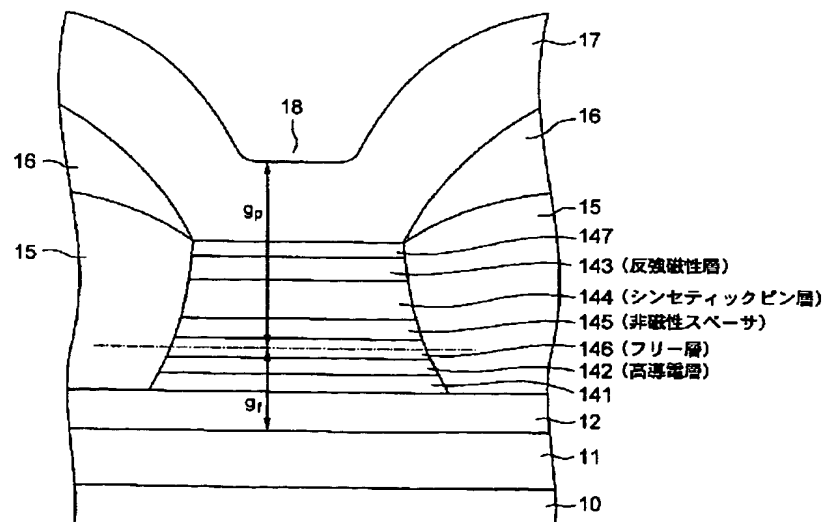
【図 50】



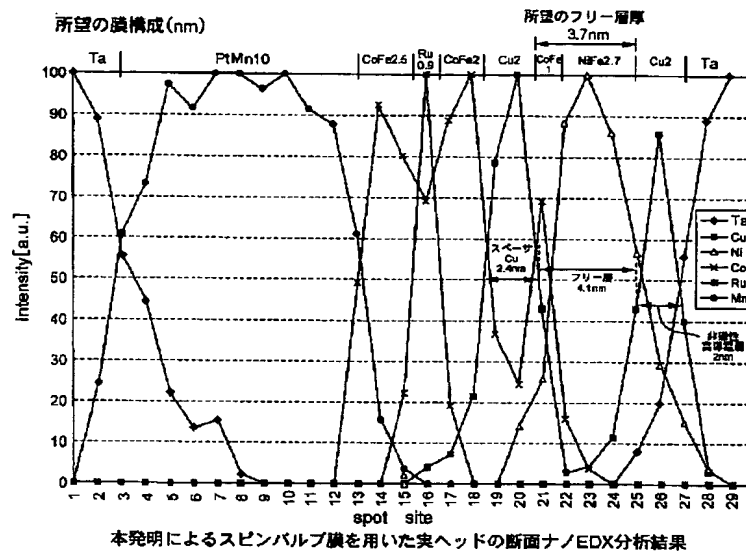
【図 51】



【図 52】



【図53】



フロントページの続き

(72)発明者 鴻井 克彦  
神奈川県川崎市幸区堀川町72番地 株式会  
社東芝川崎事業所内

(72)発明者 中村 新一  
神奈川県横浜市磯子区新杉田町8番地 株  
式会社東芝横浜事業所内

(72)発明者 吉川 将寿  
神奈川県川崎市幸区堀川町72番地 株式会  
社東芝川崎事業所内

(72)発明者 橋本 進  
神奈川県川崎市幸区堀川町72番地 株式会  
社東芝川崎事業所内

(72)発明者 佐橋 政司  
神奈川県川崎市幸区堀川町72番地 株式会  
社東芝川崎事業所内

(72)発明者 岩崎 仁志  
神奈川県川崎市幸区堀川町72番地 株式会  
社東芝川崎事業所内

(72)発明者 斉藤 和浩  
神奈川県川崎市幸区堀川町72番地 株式会  
社東芝川崎事業所内

(72)発明者 福家 ひろみ  
神奈川県川崎市幸区堀川町72番地 株式会  
社東芝川崎事業所内

Fターム(参考) 5D034 BA03 BB01 CA08

## PATENT ABSTRACTS OF JAPAN

(11)Publication number : 2000-137906

(43)Date of publication of application : 16.05.2000

1)Int.Cl. G11B 5/39

1)Application number : 11-097072

(71)Applicant : TOSHIBA CORP

2)Date of filing : 02.04.1999

(72)Inventor : FUKUZAWA HIDEAKI  
KAMIGUCHI YUZO  
KOUJI KATSUHIKO  
NAKAMURA SHINICHI  
YOSHIKAWA MASATOSHI  
HASHIMOTO SUSUMU  
SAHASHI MASASHI  
IWASAKI HITOSHI  
SAITO KAZUHIRO  
FUKUYA HIROMI

3)Priority

Priority number : 10185475  
10237821Priority date : 30.06.1998  
24.08.1998

Priority country : JP

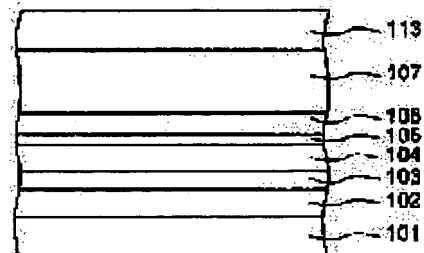
JP

54) MAGNETORESISTANCE EFFECT ELEMENT, MAGNETIC HEAD, MAGNETIC HEAD ASSEMBLY AND  
MAGNETIC RECORDING DEVICE

57)Abstract:

PROBLEM TO BE SOLVED: To obtain a magnetoresistance effect element having extremely high sensitivity while maintaining a good bias point by keeping the magnetization in one of a pair of ferromagnetic films in a second ferromagnetic layer into a desired direction, and forming a nonmagnetic high conductive layer in contact with a first ferromagnetic layer on the opposite face to the film face where the first ferromagnetic layer is in contact with a nonmagnetic spacer layer.

SOLUTION: A high conductive layer 101, free layer 102, spacer layer 103, first ferromagnetic layer 104, bonding film 105, second ferromagnetic layer 106 and antiferromagnetic film 107 are laminated. By this constitution, especially when  $H_s$  on the transfer curve is small by making the free layer 102 extremely thin, a good bias point can be obtd. by rendering all of  $H_{cu}$ ,  $H_{pin}$  and  $H_{in}$  small and satisfying  $H_{pin} - H_{in} = H_{cu}$ . By using a synthetic AF structure,  $H_{pin}$  can be decreased.



LEGAL STATUS

[Date of request for examination]

03.04.2000

late of sending the examiner's decision of rejection]

ind of final disposal of application other than the  
examiner's decision of rejection or application converted  
gistration]

late of final disposal for application]

Patent number] 3234814

late of registration] 21.09.2001

umber of appeal against examiner's decision of  
rejection]

late of requesting appeal against examiner's decision  
rejection]

late of extinction of right]

## NOTICES \*

Japan Patent Office is not responsible for any damages caused by the use of this translation.

This document has been translated by computer. So the translation may not reflect the original precisely.

\*\*\*\* shows the word which can not be translated.

In the drawings, any words are not translated.

## CLAIMS

Claim(s)]

Claim 1] The nonmagnetic spacer layer characterized by providing the following, and the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were separated by the aforementioned non-magnetic-material spacer layer, \*\*\*\*\* and the ferromagnetic layer of the above 1st have the magnetization direction which accomplishes the angle to which it is received in the magnetization direction of the ferromagnetic layer of the above 2nd when an impression magnetic field is zero. the ferromagnetic layer of the above 2nd The magnetoresistance-effect element containing the ferromagnetic film of the couple mutually combined in antiferromagnetism, and the joint film which combines these in antiferromagnetism, separating the ferromagnetic film of the aforementioned couple. A means to maintain one magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired. The nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the film surface which the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an opposite side.

Claim 2] The aforementioned nonmagnetic quantity conductive layer is a magnetoresistance-effect element according to claim 1 characterized by containing the element whose value of the specific resistance in the room temperature of a bulk state is 10 or less microhm-cm.

Claim 3] The thickness of the ferromagnetic layer of the above 1st is a magnetoresistance-effect element according to claim 1 or 2 characterized by 0.5nm or more being 4.5nm or less.

Claim 4] Wave asymmetry  $(V1-V2)/(V1+V2)$  expressed with the absolute value V1 of the reproduction output in a right signal magnetic field and the absolute value V2 of the reproduction output in a negative signal magnetic field so that it may become 0.1 or less 0.1 or more minus plus The magnetoresistance-effect element of any one publication of the claim 1-3 characterized by setting up the thickness of the aforementioned nonmagnetic quantity conductive layer, and the thickness of the ferromagnetic layer of the above 2nd.

Claim 5] Nonmagnetic spacer layer. The ferromagnetic layer of the above 1st is the magnetization direction which accomplishes the angle to which it has received in the magnetization direction of the ferromagnetic layer of the above 1st and when it has the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were separated by the aforementioned non-magnetic-material spacer layer and an impression magnetic field is zero. A means to be the magnetoresistance-effect element equipped with the above, and to maintain one magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired, The nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the film surface which the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an opposite side,

\*\*\* and wave asymmetry  $(V1-V2)/(V1+V2)$  expressed with the absolute value V1 of the reproduction output in a right signal magnetic field and the absolute value V2 of the reproduction output in a negative signal magnetic field further It is characterized by setting up the thickness of the aforementioned nonmagnetic quantity conductive layer, and the thickness of the ferromagnetic layer of the above 2nd so that it may become 0.1 or less 0.1 or more minus plus.

Claim 6] The thickness of the aforementioned nonmagnetic quantity conductive layer converted into Cu of 10microhm-cm of specific resistance  $t$  (HCL), When magnetic thickness which converted the thickness of the ferromagnetic film of the aforementioned couple in the ferromagnetic layer of the above 2nd by the saturation magnetization of 1T is set to  $t_m$  (pin1) and  $t_m$  (pin2) ( $t_m$ (pin1) > it is referred to as  $t_m$  (pin2)), respectively The magnetoresistance-effect element of any one publication of the claim 1-5 characterized by satisfying  $0.5 \text{ nm} \leq t_m(\text{pin1}) - t_m(\text{pin2}) + t(\text{HCL}) \leq 4 \text{ nm}$  and  $t(\text{HCL}) \geq 0.5 \text{ nm}$ .

Claim 7] Nonmagnetic spacer layer. The ferromagnetic layer of the above 1st is the magnetization direction which accomplishes the angle to which it has received in the magnetization direction of the ferromagnetic layer of the above 1st and when it has the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were separated by the

mentioned non-magnetic-material spacer layer and an impression magnetic field is zero. A means to be the magnetoresistance-effect element equipped with the above, and to maintain one magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired, The nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the film surface which the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an opposite side, \*\* and further the thickness of the aforementioned nonmagnetic quantity conductive layer converted into Cu of specific resistance  $10 \mu\Omega/\text{cm}$  (HCL), When magnetic thickness which converted the thickness of the ferromagnetic film of the aforementioned couple in the ferromagnetic layer of the above 2nd by the saturation magnetization of 1T is set to  $t_m(\text{pin1})$  and  $t_m(\text{pin2})$  ( $t_m(\text{pin1}) > t_m(\text{pin2})$ ), respectively It is characterized by satisfying  $0.5 \text{ nm} \leq t_m(\text{pin1}) - t_m(\text{pin2}) + t(\text{HCL}) \leq 4 \text{ nm}$  and  $t(\text{HCL}) \geq 0.5 \text{ nm}$ .

Claim 8] The aforementioned nonmagnetic quantity conductive layer Copper (Cu), gold (Au), silver (Ag), a ruthenium (Ru), Iridium (Ir), a rhenium (Re), a rhodium (Rh), platinum (Pt), The magnetoresistance-effect element of any one publication of the claim 1-7 characterized by being the metal membrane which contains at least a kind of metallic element chosen from the group which consists of palladium (Pd), aluminum (aluminum), an osmium (Os), and nickel (nickel).

Claim 9] Nonmagnetic spacer layer. The ferromagnetic layer of the above 1st is the magnetization direction which accomplishes the angle to which it has received in the magnetization direction of the ferromagnetic layer of the above 2nd when it has the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were separated by the aforementioned non-magnetic-material spacer layer and an impression magnetic field is zero. A means to be the magnetoresistance-effect element equipped with the above, and to maintain one magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired, It has the nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the film surface which the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an opposite side, and the aforementioned nonmagnetic quantity conductive layer is further characterized by being formed from the cascade screen which carried out the laminating of the film more than two-layer at least.

Claim 10] The magnetoresistance-effect element according to claim 9 characterized by the film which touches the ferromagnetic layer of the above 1st among the aforementioned cascade screens containing copper (Cu).

Claim 11] The magnetoresistance-effect element according to claim 10 characterized by including at least a kind of element chosen from the group which the film which does not touch the ferromagnetic layer of the above 1st among the aforementioned cascade screens becomes from a ruthenium (Ru), a rhenium (Re), a rhodium (Rh), palladium (Pd), platinum (Pt), iridium (Ir), and an osmium (Os).

Claim 12] The magnetoresistance-effect element of any one publication of the claim 1-11 characterized by touching the aforementioned nonmagnetic quantity conductive layer in the ferromagnetic layer of the above 1st, and the field of an opposite side, and having the layer which contains at least a kind of element chosen from the group which consists of a tantalum (Ta), titanium (Ti), a zirconium (Zr), a tungsten (W), a hafnium (Hf), and molybdenum (Mo).

Claim 13] The ferromagnetic layer of the above 1st is the magnetoresistance-effect element of any one publication of the claim 1-12 characterized by the bird clapper from the cascade screen of the alloy layer containing a ferronickel (NiFe), and the layer containing cobalt (Co).

Claim 14] The ferromagnetic layer of the above 1st is the magnetoresistance-effect element of any one publication of the claim 1-12 characterized by the bird clapper from the alloy layer containing cobalt iron (CoFe).

Claim 15] Nonmagnetic spacer layer. The ferromagnetic layer of the above 1st is the magnetization direction which accomplishes the angle to which it has received in the magnetization direction of the ferromagnetic layer of the above 2nd when it has the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were separated by the aforementioned non-magnetic-material spacer layer and an impression magnetic field is zero. The antiferromagnetism layer as a means to be the magnetoresistance-effect element equipped with the above, and to maintain one magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired, The nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the film surface which the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an opposite side, It \*\*\*\* and is  $\text{XzMn}_{1-z}$  (X here) as a material of the aforementioned antiferromagnetic substance layer. at least a kind of element chosen from the group which consists of iridium (Ir), a ruthenium (Ru), a rhodium (Rh), platinum (Pt), palladium (Pd), and a rhenium (Re) -- carrying out -- the composition ratio z -- more than 5 atom % -- below 40 atom % -- it is -- it is characterized by using

Claim 16] Nonmagnetic spacer layer. The ferromagnetic layer of the above 1st is the magnetization direction which accomplishes the angle to which it has received in the magnetization direction of the ferromagnetic layer of the above 2nd when it has the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were separated by the

orementioned non-magnetic-material spacer layer and an impression magnetic field is zero. The antiferromagnetism layer as a means to be the magnetoresistance-effect element equipped with the above, and to maintain one magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2ndwards desired, The nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the m surface which the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an opposite side, It \*\*\*\* and is characterized by using  $XzMn_{1-z}$  (X considering as a kind of element chosen from the group which consists of platinum (Pt) and palladium (Pd) at least here, and the composition ratio z being below 65 atom % more than 40 atom %) as a material of the aforementioned antiferromagnetism layer.

Claim 17] The aforementioned non-magnetic-material spacer layer is the magnetoresistance-effect element of any one publication of the claim 1-16 to which it consists of a metal layer containing copper (Cu), and the thickness is characterized by 1.5nm or more being 2.5nm or less.

Claim 18] It is the magnetoresistance-effect element according to claim 1 or 2 to which the difference of the magnetic thickness whose ferromagnetic film of the aforementioned couple those thickness of the ferromagnetic film of the aforementioned couple combined [ aforementioned ] in antiferromagnetism is equal, its ferromagnetic film which touches the aforementioned nonmagnetic spacer side is thicker, and is the product of each thickness and saturation [AG is characterized by 0 or more nmTs being 2 or less nmT.

Claim 19] The aforementioned joint film which combines the ferromagnetic film of the aforementioned couple in antiferromagnetic substance is a magnetoresistance-effect element according to claim 1 or 2 to which it consists of a ruthenium (Ru), and the thickness is characterized by 0.8nm or more being 1.2nm or less.

Claim 20] The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, And it sets for the magnetoresistance-effect element which is the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film. It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes from the ferromagnetic layer B arranged at the aforementioned ferromagnetic layer which has been arranged at the aforementioned nonmagnetic interlayer side ] A, and antiferromagnetism layer side through a magnetic coupling layer. The aforementioned antiferromagnetism layer is a magnetoresistance-effect element to which orientation of the maximum \*\*\*\* is carried out, and it is characterized by the bird clapper so that the locking curve half-value width of the maximum \*\*\*\* peak may become 8 degrees or less.

Claim 21] The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, In the magnetoresistance-effect element which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film, and the vertical bias layer of the couple to the aforementioned huge magnetoresistance-effect film The aforementioned magnetization fixing layer is a magnetoresistance-effect element characterized by the electrode of the aforementioned couple having an electrode spacing narrower than the interval of the aforementioned vertical bias layer by coming to carry out antiferromagnetism combination of the ferromagnetic layer of a couple which consists of a ferromagnetic layer B by the side of the ferromagnetic layer A by the side of the aforementioned nonmagnetic interlayer, and the aforementioned antiferromagnetism layer through a magnetic coupling layer.

Claim 22] The nonmagnetic interlayer of at least one layer. The electrode of the couple which supplies sense current to the spin bulb film which has at least the two-layer magnetic layer arranged through the aforementioned nonmagnetic interlayer, and the aforementioned spin bulb film. It is the magnetoresistance-effect element equipped with the above. The aforementioned spin bulb film The improvement layer in the magnetoresistance effect which turns into the aforementioned nonmagnetic interlayer of the aforementioned magnetic layer from the cascade screen of two or more metal membranes which touch the field of an opposite side, It has the non-magnetic layer which has the ground function or protection feature which touches the aforementioned magnetic layer of the aforementioned improvement layer in the magnetoresistance effect with the field of an opposite side. And it is characterized by the element which mainly constitutes the metal membrane which touches the aforementioned magnetic layer among the aforementioned improvement layers in the magnetoresistance effect not dissolving with the element which mainly constitutes the aforementioned magnetic layer.

Claim 23] The magnetic head characterized by to provide a bottom magnetic-shielding layer, the bottom reproduction magnetic-gap layer a layer was prepared on the aforementioned bottom magnetic-shielding layer, the magnetoresistance-effect element of any one publication of the claim 1-22 prepared on the aforementioned bottom

reproduction magnetic-gap layer, and the bottom reproduction magnetic-gap layer prepared on the aforementioned magnetoresistance-effect element and the top magnetic-shielding layer prepared on the aforementioned top magnetic-layer.

claim 24] The magnetic head according to claim 23 characterized by the irregularity of the front face of the aforementioned bottom reproduction magnetic-gap layer in a magnetic force sensor being smaller than the thickness of aforementioned joint film.

claim 25] The aforementioned nonmagnetic spacer layer is minded from the center which saw the ferromagnetic layer the above 1st in the direction of thickness. The aforementioned top magnetic-shielding layer and the aforementioned bottom magnetic-shielding layer either, without minding the aforementioned nonmagnetic spacer layer from the center which saw D1 and the ferromagnetic layer of the above 1st for the distance which results in the aforementioned top magnetic-shielding layer or the aforementioned bottom magnetic-shielding layer in the direction of thickness when distance which reaches another side is set to D2  $D1 > D2$ . The magnetic head according to claim 23 or 24 characterized by  $D1 > D2$ .

claim 26] The magnetic head of any one publication of the claim 23-25 characterized by having further the recording head which has the bottom magnetic pole which was communalized with the aforementioned top magnetic-shielding layer, and was prepared, the record magnetic-gap layer prepared on the aforementioned bottom magnetic pole, and the bottom magnetic pole prepared on the aforementioned record magnetic-gap layer.

claim 27] The magnetic-head assembly characterized by providing the head slider which has the magnetic head according to claim 26, and the arm which has the suspension in which the aforementioned head slider was carried.

claim 28] The magnetic recording medium characterized by providing the head slider which has the magnetic head according to claim 27 which reads a signal by detecting the magnetic field which writes in a signal and is generated from the aforementioned magnetic-recording medium by impressing a magnetic field to a magnetic-recording medium and the aforementioned magnetic-recording medium.

---

translation done.]

OTICES \*

an Patent Office is not responsible for any  
ages caused by the use of this translation.

his document has been translated by computer. So the translation may not reflect the original precisely.

\*\*\* shows the word which can not be translated.

1 the drawings, any words are not translated.

## TAILED DESCRIPTION

etailed Description of the Invention]

01]

ie technical field to which invention belongs] this invention relates to the magnetoresistance-effect element using spin bulb film with which this invention has high sensitivity and high-reliability in a detail, the magnetic head, a gnetic-head assembly, and a magnetic recording medium more about a magnetoresistance-effect element, the gnetic head, a magnetic-head assembly, and a magnetic recording medium.

02]

escription of the Prior Art] The expectation for the magnetic head (MR head) using the magnetoresistance effect (R) which can take out a big output from small and large capacity-ization of a magnetic-recording medium being vanced in recent years is growing. As a MR film used as the basic component of such an MR head It has the igned magnetic multilayer of the sandwich structure of a magnetic layer / non-magnetic layer / magnetic layer especially. one igned magnetic layer -- exchange bias -- doing -- magnetization -- fixing (a "magnetization fixing layer" --) Flux reversal of e magnetic layer of another side called a "fixing layer" or a "pin layer" is carried out by the external magnetic field igned a "magnetosensitive layer" or a "free layer"). The spin bulb film in which the huge magnetoresistance effect (MR) is shown by relative angle change of the magnetization direction of these two magnetic layers attracts attention.

003] As other MR films, an anisotropy magnetoresistance-effect film (AMR film), an artificial grid film, etc. which nsist of a NiFe alloy etc. are known. MR rate of change of a spin bulb film is 4% or more, although it is small mpared with an artificial grid film, and it is fully large as compared with the AMR film. Furthermore, since a spin lb film can saturate magnetization with a low magnetic field, it fits the MR head. It has a practically great hope for e MR head using such a spin bulb film. That is, in magnetic recording, such as a magnetic disk, the high sensitivity agnetic head which used the huge magnetoresistance effect (GMR), i.e., a GMR head, is indispensable to advance nsification of recording density.

004] The spin bulb film which consists of a magnetization free layer (free layer), a nonmagnetic interlayer, a agnetization fixing layer (pin layer), and an antiferromagnetism layer is used for an early GMR head as a GMR ement. however -- if the thickness of a magnetization free layer is reduced in order to aim at improvement in nsitivity indispensable to narrow the width of recording track of record and to perform densification -- the disclosure agnetic field from a magnetization fixing layer -- the shift of the operating point -- bringing -- coming -- this shift ount -- the yield -- good -- a current magnetic field -- an amendment -- things become difficult

005] The so-called laminating ferry fixing layer ("SyAF", "synthetic AF", or an "antiferromagnetism fixing layer" is igned henceforth) which constituted the magnetization fixing layer from a two-layer ferromagnetic layer which carries at antiferromagnetism combination through a magnetic coupling layer on the other hand is proposed (JP,7-169026,A). ince the operating point is theoretically made to zero by the disclosure magnetic field in this antiferromagnetism xing layer, reservation of the operating point is easy.

006] Namely, if a ferromagnetic layer A and antiferromagnetism layer side is used as the ferromagnetic layer B, the onmagnetic interlayer side of two ferromagnetic layers of this magnetization fixing layer The magnetic thickness, i.e., ickness, x saturation magnetization of the ferromagnetic layer A and the ferromagnetic layer B in equal SyAF Since e disclosure magnetic field of the ferromagnetic layer A and the ferromagnetic layer B is negated mutually, a isclosure magnetic field serves as zero substantially and a magnetization fixing layer stops inducing a magnetic field e stability of fixing magnetization is [ to / near / where the exchange bar chair of an antiferromagnetism layer isappears / the blocking temperature Tb ] good -- etc. -- it has a big merit

0007]

Problem(s) to be Solved by the Invention] However, there were various problems in these magnetoresistance-effect

nents by which the conventional proposal is made.

08] First, in order to raise [ 1st ] sensitivity, when the free layer was thin-film-ized, there was a problem that the s point design at the time of sense current energization became difficult.

09] Since magnetization of SyAF becomes unstable in the temperature more than blocking temperature ( $T_b$ ) the l, if static discharge (ESD) current flows into a GMR element, a fixing layer will be momentarily heated by the perature more than  $T_b$ , and the problem that fixing of magnetization will be confused arises. It is required to add strong magnetic field (usually several more than kOe) exceeding the antiferromagnetism joint magnetic field ough the magnetic coupling layer which raises temperature to more than  $T_b$  and moreover constitutes [ 3rd ] SyAF order to fix magnetization. For this reason, when temperature is raised to more than  $T_b$  using the high iferromagnetic substance of  $T_b$  for fixing of magnetization as an antiferromagnetism layer, there is a problem that duce diffusion and antiferromagnetism combination falls between the ferromagnetic layers which adjoin the gnetic coupling layer of SyAF.

10] In order to add the strong magnetic field (JP,9-16920,A 15 kOe(s)) exceeding the antiferromagnetism joint gnetic field which minds a magnetic coupling layer where a temperature rise is carried out to the 4th, a huge gnetization fixing thermal treatment equipment is needed.

11] Although magnetization fixing will become easy in order to sympathize with an external magnetic field if it is ide SyAF of unsymmetrical structure which changed the magnetic thickness of 2 ferromagnetism layers combined th the 5th in antiferromagnetism in the pin layer Before and after the heat-resistant requirements for the magnetic ad needed in future high-density record, i.e., 200 degrees C, since the thermal resistance which came out on the other nd and was excellent in symmetrical SyAF will be lost, the problem that filling becomes difficult produces that gnetization fixing is stable. Moreover, since it will be accompanied by generating of a disclosure magnetic field, the oblem that the cure of reservation of the operating point is also needed is also produced.

12] There is also a trouble of 6th producing diverging of sense current and reducing the resistance rate of change as 3MR element since a magnetic coupling layer and the ferromagnetic layer B are low resistance even if SyAF is a mmetrical system and it is an unsymmetrical system.

13] furthermore, six troubles of having enumerated above -- (3) which runs short of MR rate of change when (1) ermal resistance aims at much more improvement in bad (receiving especially initial process annealing) (2) production sensitivity -- when a magnetosensitive layer was constituted from a CoFe alloy-layer monolayer from rich comparatively big MR rate of change is obtained, magnetostriction control was not completed, but there were so problems -- good soft magnetic characteristics are not obtained -- [ in addition, ]

14] this invention is made based on recognition of the various technical problems mentioned above. That is, the sign of the bias point is easy for the purpose, and is to offer the magnetoresistance-effect element which has high nsitivity and high-reliability, the magnetic head, a magnetic-head assembly, and a magnetic recording medium.

15] Means for Solving the Problem] In order to attain the above-mentioned purpose, the magnetoresistance-effect element of this invention It has a nonmagnetic spacer layer, and the 1st ferromagnetic layer and the 2nd ferromagnetic layer hich were separated by the aforementioned non-magnetic-material spacer layer. the ferromagnetic layer of the above st It has the magnetization direction which accomplishes the angle to which it has received in the magnetization rection of the ferromagnetic layer of the above 2nd when an impression magnetic field is zero. the ferromagnetic yer of the above 2nd It is a magnetoresistance-effect element containing the ferromagnetic film of the couple utually combined in antiferromagnetism, and the joint film which combines these in antiferromagnetism, separating ie ferromagnetic film of the aforementioned couple. It is characterized by having the nonmagnetic quantity nductive layer which touches the 1st ferromagnetic layer in respect of the film surface which a means to maintain ne magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2nd owards desired, and the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, nd an opposite side.

16] A magnetoresistance-effect element with very high sensitivity is realizable with the above-mentioned omposition, maintaining the good bias point.

17] As a gestalt of desirable implementation of the above-mentioned composition, the aforementioned nonmagnetic uantity conductive layer becomes realizable [ the high MR rate of change by low Hcu realization and the spin-filter effect in an ultra-thin free layer ] by containing the element whose value of the specific resistance in the room emperature of a bulk state is 10 or less microomegacm.

18] moreover, it is characterized by the thickness which is the ferromagnetic layer of the above 1st being 0.5nm or ore 4.5nm or less as composition suitable for realizing the effect of MR rate-of-change elevation by the object for igh-density record, and the spin-filter effect by the nonmagnetic quantity conductive layer

- 019] Moreover, wave asymmetry  $(V1-V2)/(V1+V2)$  expressed with the absolute value V1 of the reproduction output in a right signal magnetic field and the absolute value V2 of the reproduction output in a negative signal magnetic field characterized by setting up the thickness of the aforementioned nonmagnetic quantity conductive layer, and the thickness of the ferromagnetic layer of the above 2nd so that it may become 0.1 or less 0.1 or more minus plus. In order to make wave asymmetry 0.1 or less 0.1 or more minus plus, it is not necessary to necessarily adopt SyAF and a pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs. 3. It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.
- 020] Moreover, it is t (HCL) (here) about the thickness of the aforementioned nonmagnetic quantity conductive layer. It  $t_m(s)$  (pin1). it converted in Cu layer of 10micro  $\Omega$ cm of specific resistance -- the magnetic thickness which converted the thickness of the ferromagnetic film of the aforementioned couple in the ferromagnetic layer of the above 2nd by the saturation magnetization of 1T, respectively When referred to as  $t_m$  (pin2) ( $t_m(\text{pin1}) >$  it is referred as  $t_m$  (pin2)), it is characterized by satisfying  $0.5 \text{ nm} \leq t_m(\text{pin1}) - t_m(\text{pin2}) + t(\text{HCL}) \leq 4 \text{ nm}$  and  $t(\text{HCL}) \geq 0.5 \text{ nm}$ . As long as it satisfies this relation, you may use  $t_m(\text{pin2}) = 0$ , i.e., the pin layer of a monolayer. By satisfying the above-mentioned relation, wave asymmetry becomes 0.1 or less plus by 0.1 or more minus, and high MR can be realized.
- 021] Moreover, the ferromagnetic layer of the above 1st is characterized by the magnetic thickness which is the product of the thickness and saturation magnetization being less than 5 nmTs.
- 022] Moreover, the copper which becomes advantageous [ the aforementioned nonmagnetic quantity conductive layer ] to having the conditions of low  $H_{in}$  realization (Cu), Gold (Au), silver (Ag), a ruthenium (Ru), iridium (Ir), It is characterized by being the metal membrane which contains at least a kind of metallic element chosen from the group which consists of a rhenium (Re), a rhodium (Rh), platinum (Pt), palladium (Pd), aluminum (aluminum), an osmium (Os), and nickel (nickel).
- 023] Moreover, the aforementioned nonmagnetic quantity conductive layer is characterized by being formed from the cascade screen which carried out the laminating of the film more than two-layer at least for low  $H_{in}$  and soft-magnetism property control.
- 024] When using this cascade screen, it is not necessary to necessarily adopt SyAF and the pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs. 3. It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.
- 025] Moreover, the film which touches the ferromagnetic layer of the above 1st among the aforementioned cascade screens is characterized by including copper (Cu) as a material which was excellent especially for high MR rate of change, low  $H_{cu}$  realization, and soft-magnetism realization.
- 026] Moreover, the film which does not touch the ferromagnetic layer of the above 1st among the aforementioned cascade screens is characterized by including at least a kind of element chosen from the group which consists of a ruthenium (Ru), a rhenium (Re), a rhodium (Rh), palladium (Pd), platinum (Pt), iridium (Ir), and an osmium (Os) as a material excellent in low  $H_{in}$ , low  $H_{cu}$ , and especially soft-magnetism control.
- 027] Moreover, thickness of the aforementioned nonmagnetic quantity conductive layer is characterized by 0.5nm or more being 5nm or less for realization of low  $H_{cu}$  and high MR rate of change.
- 028] Moreover, in order to realize low  $H_{in}$  and high MR rate of change, it is characterized by touching the aforementioned nonmagnetic quantity conductive layer in the ferromagnetic layer of the above 1st, and the field of an opposite side, and having the layer which contains at least a kind of element chosen from the group which consists of a tantalum (Ta), titanium (Ti), a zirconium (Zr), a tungsten (W), a hafnium (Hf), and molybdenum (Mo).
- 029] Moreover, the ferromagnetic layer of the above 1st is characterized by the bird clapper from the cascade screen of the alloy layer containing a ferronickel (NiFe), and the layer containing cobalt (Co) high MR rate of change and for soft-magnetism realization.
- 030] Moreover, the ferromagnetic layer of the above 1st is characterized by the bird clapper from the alloy layer containing cobalt iron (CoFe) high MR rate of change and for soft-magnetism realization.
- 031] Moreover, it is characterized by using an antiferromagnetic substance layer as a means to maintain the ferromagnetic layer of the above 2nd towards desired for magnetization fixing of the ferromagnetic layer of the above 2nd. Although it is desirable that it is SyAF as for the 2nd ferromagnetic layer, the ferromagnetic layer of a monolayer is sufficient as it. In the case of a monolayer, it is desirable for the magnetic thickness to be 3.6 or less nmTs in 0.5 or more nmTs.
- 032] Moreover, it is  $X_z\text{Mn}1-z$  (X here) as a material of the aforementioned antiferromagnetic substance layer also after process heat treatment because of high MR rate-of-change realization. at least a kind of element chosen from the group which consists of iridium (Ir), a ruthenium (Ru), a rhodium (Rh), platinum (Pt), palladium (Pd), and a rhenium

e) -- carrying out -- the composition ratio  $z$  -- more than pentatomic % -- below 40 atom % -- it is -- it is characterized by using Also in this case, it is not necessary to necessarily adopt SyAF and the pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs. 3. It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.

033] Moreover, in order to \*\* high MR rate of change, it is characterized by using  $XzMn_{1-z}$  (X considering as a kind of element chosen from the group which consists of platinum (Pt) and palladium (Pd) at least here, and the composition ratio  $z$  being below 65 atom % more than 40 atom %) as a material of the aforementioned antiferromagnetism layer. so in this case, it is not necessary to necessarily adopt SyAF and the pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs. It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.

034] moreover, in order to realize realizing high MR rate of change, using more effectively the effect of the high MR rate of change by the nonmagnetic quantity conductive layer, and low  $H_{cu}$ , the aforementioned non-magnetic-material layer consists of a metal layer containing copper (Cu), and the thickness makes it the feature to 1.5nm or more or 2.5nm or less

035] Moreover, the ferromagnetic film of the aforementioned couple combined [ aforementioned ] in antiferromagnetism for the purpose of realizing high MR and raising an ESD-proof property and the thermal resistance of a pin fixing layer Those thickness is equal, the ferromagnetic film which touches the aforementioned nonmagnetic layer side is thicker, and the difference of the magnetic thickness whose ferromagnetic film of the aforementioned couple is the product of each thickness and saturation MAG is characterized by 0 or more nmTs being 2 or less nmT.

036] Moreover, the aforementioned joint film which combines the ferromagnetic film of the aforementioned couple and antiferromagnetic substance consists of a ruthenium (Ru), and the thickness is characterized by 0.8nm or more being 2nm or less.

037] On the other hand, the magnetoresistance-effect head of invention of the 1st of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, And it sets on the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film. It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes from the ferromagnetic layer B arranged at the aforementioned ferromagnetic layer which has been arranged at the aforementioned nonmagnetic interlayer side ] A, and antiferromagnetism layer side through a magnetic coupling layer. The aforementioned antiferromagnetism layer is a magnetoresistance-effect head to which orientation of the maximum \*\*\*\* is carried out, and it is characterized by the bird clapper so that the rocking curve half-value width of the maximum \*\*\*\* peak may become 8 degrees or less.

038] The magnetoresistance-effect head of invention of the 2nd of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, And it sets on the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film. It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes from the ferromagnetic layer B arranged at the aforementioned ferromagnetic layer [ which has been arranged at the aforementioned nonmagnetic interlayer side ] A, and antiferromagnetism layer side through a magnetic coupling layer. or the aforementioned antiferromagnetism layer, the switched connection constant  $J$  with the aforementioned ferromagnetic layer [ in / 200 degrees C / thickness is 20nm or less and ] B is 0.02 erg/cm<sup>2</sup>. It is the magnetoresistance-effect head characterized by being above.

039] The magnetoresistance-effect head of invention of the 3rd of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, And it sets on the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film. It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes

om the ferromagnetic layer B arranged at the aforementioned ferromagnetic layer [ which has been arranged at the aforementioned nonmagnetic interlayer side ] A, and antiferromagnetism layer side through a magnetic coupling layer. thickness is 20nm or less, and the aforementioned antiferromagnetism layer is  $Zx Mn 1-x$  (it Ir(s) Z). It is the at least 1 sort chosen from Rh, Ru, Pt, Pd, Co, and nickel.  $0 < x < 0.4$  and  $Zx Mn 1-x$  (Z is at least one sort chosen from Pt, Pd, and nickel) It is  $0.4 \leq x \leq 0.7$  or the magnetoresistance-effect head characterized by the thing of  $Zx Cr 1-x$  (at least one sort,  $0 < x < 1$  as which Z was chosen from Mn, aluminum, Pt, Pd, Cu, Au, Ag, Rh, Ir, and Ru) included for any one sort at least.

0040] The magnetoresistance-effect head of invention of the 4th of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, In the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film, and the vertical bias layer of the couple to the aforementioned huge magnetoresistance-effect film It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes from the ferromagnetic layer B by the side of the ferromagnetic layer A by the side of the aforementioned nonmagnetic interlayer, and the aforementioned antiferromagnetism layer through a magnetic coupling layer. The electrode of the aforementioned couple is a magnetoresistance-effect head characterized by having an electrode spacing narrower than the interval of the aforementioned vertical bias layer.

0041] In addition, the composition of the 1st or 4th magnetoresistance-effect head mentioned above is also applicable to composition of a magnetoresistance-effect element as it is.

0042] Moreover, the magnetic disk drive equipment of this invention is characterized by providing the magnetoresistance-effect head of the above-mentioned this invention. And invention of the magnetic disk drive equipment of this application is characterized by having the mechanism in which magnetization of the aforementioned magnetization fixing layer is made to fix in the predetermined direction, using the magnetic field generated by applying current to the aforementioned magnetoresistance-effect element of the magnetoresistance-effect head of the above-mentioned this invention.

0043] Furthermore, the manufacture method of the magnetoresistance-effect head of this invention is after membrane formation of the aforementioned huge magnetoresistance-effect film, and before it performs patterning, it is characterized by performing heat treatment among a magnetic field and making the direction of magnetization fix in the predetermined direction to the aforementioned ferromagnetic layer A and the aforementioned ferromagnetic layer B.

0044] On the other hand, the magnetoresistance-effect element based on other forms of this invention The spin bulb film which has at least the two-layer magnetic layer arranged through the nonmagnetic interlayer of at least one layer, and the aforementioned nonmagnetic interlayer, In the magnetoresistance-effect element possessing the electrode of the couple which supplies sense current to the aforementioned spin bulb film the aforementioned spin bulb film The improvement layer in the magnetoresistance effect which turns into the aforementioned nonmagnetic interlayer of the aforementioned magnetic layer from the cascade screen of two or more metal membranes which touch the field of an opposite side, It has the non-magnetic layer which has the ground function or protection feature which touches the aforementioned magnetic layer of the aforementioned improvement layer in the magnetoresistance effect with the field of an opposite side. And it is characterized by the element which mainly constitutes the metal membrane which touches the aforementioned magnetic layer among the aforementioned improvement layers in the magnetoresistance effect not dissolving with the element which mainly constitutes the aforementioned magnetic layer.

0045] The magnetoresistance-effect element of this invention With or the nonmagnetic interlayer of at least one layer and the magnetoresistance-effect element possessing the spin bulb film which has at least the two-layer magnetic layer arranged through the aforementioned nonmagnetic interlayer, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film The aforementioned spin bulb film has the improvement layer in the magnetoresistance effect which turns into the aforementioned nonmagnetic interlayer of the aforementioned magnetic layer from the metaled monolayer or metaled cascade screen which touches the field of an opposite side. And while the element which mainly constitutes the aforementioned improvement layer in the magnetoresistance effect does not dissolve with the element which mainly constitutes the aforementioned magnetic layer which the aforementioned improvement layer in the magnetoresistance effect touches, the aforementioned improvement layer in the magnetoresistance effect is characterized by having the alloy layer of a noble-metals system at least.

0046] The magnetoresistance-effect element of this invention With or the nonmagnetic interlayer of at least one layer and the magnetoresistance-effect element possessing the spin bulb film which has at least the two-layer magnetic layer

inged through the aforementioned nonmagnetic interlayer, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film While the aforementioned magnetic layer of at least one layer is arranged through the improvement layer in the magnetoresistance effect which has at least the cascade screen of two or more metals, and one side of an alloy layer It is characterized by the element which has two or more ferromagnetics combined magnetically, and mainly constitutes the aforementioned improvement layer in the magnetoresistance effect dissolving with the element which mainly constitutes the aforementioned ferromagnetic which the aforementioned improvement layer in the magnetoresistance effect touches.

047] Here, in three sorts of above-mentioned magnetoresistance-effect elements, the improvement layers in the magnetoresistance effect are an interface with a magnetic layer, an interface in a cascade screen, an interface with a non-magnetic layer or the non-magnetic layer as a protective layer, etc., show the electronic specular reflection effect as an example of an effect, and, thereby, raise the magnetoresistance effect of a spin bulb film. Moreover, when a free layer comes thin, high MR rate of change can be maintained by canceling dispersion diffusive in an electron and raising permeability of rise spin by the improvement layer in the magnetoresistance effect here acting as a nonmagnetic quantity conductive layer mentioned above, and forming the interface of an ultra-thin free layer and a nonmagnetic quantity conductive layer with the combination of material [ \*\*\*\* / un-]. Since it is an interface [ \*\*\*\* / un-], with heat treatment etc., an interface is stable and can cancel decline in MR rate of change. The improvement layer in the magnetoresistance effect in this invention is not based only on the specular reflection effect, and control of the crystal structure of a spin bulb film, improvement in the magnetoresistance effect by reduction of a magnetostriction, etc. and so on about further so that it may explain in full detail behind.

048] Moreover, in three sorts of above-mentioned magnetoresistance-effect elements, when the magnetic layer which the improvement layer in the magnetoresistance effect touches consists of Co or a Co alloy as concrete composition of the improvement layer in the magnetoresistance effect, it is characterized by including at least one sort of elements chosen from Cu, Au, and Ag. Moreover, when the magnetic layer which the improvement layer in the magnetoresistance effect touches consists of a nickel alloy, it is characterized by including at least one sort of elements chosen from Ru, Ag, and Au. The thing containing elements, such as Cu, Au, Ag, Pt, Rh, Ru, aluminum, Ti, Zn, Hf, Ir, and Ir, is applicable to the improvement layer in the magnetoresistance effect.

049] When applying an alloy layer to the improvement layer in the magnetoresistance effect, as an alloy which constitutes it, an AuCu alloy, a PtCu alloy, an AgPt alloy, an AuPd alloy, an AuAg alloy, etc. are illustrated. Moreover, when applying a cascade screen to the improvement layer in the magnetoresistance effect, as for a cascade screen, it is desirable to have two or more metal membranes which have the relation of dissolution mutually. However, it is also possible to use the cascade screen of two or more metal membranes which have a non-dissolving relation.

050] Furthermore, in three sorts of above-mentioned magnetoresistance-effect elements, this is arranged in contact with a magnetic layer, using a magnetic layer, and the cascade screen and alloy layer of a metal membrane which have non-dissolving relation as an improvement layer in the magnetoresistance effect. Moreover, when a free layer comes thin, high MR rate of change can be maintained by canceling dispersion diffusive in an electron and raising permeability of rise spin also here by the improvement layer in the magnetoresistance effect acting as a nonmagnetic quantity conductive layer mentioned above, and forming the interface of an ultra-thin free layer and a nonmagnetic quantity conductive layer with the combination of material [ \*\*\*\* / un-]. Since it is an interface [ \*\*\*\* / un-], with heat treatment etc., an interface is stable and can cancel decline in MR rate of change. The interface of the improvement layer in these magnetoresistance effects and a magnetic layer is excellent in composition \*\*\*\*\* based on a non-dissolving relation, and this state is further maintained after a thermal process. Therefore, the improvement layer in the magnetoresistance effect can be effectively operated as a specular reflection film (interface reflective film), and contributes to the improvement in a property of a magnetoresistance-effect element greatly. Since the improvement effect of this magnetoresistance-effect property is not lost after a thermal process, it can offer the magnetoresistance-effect element excellent in thermal resistance. In other words, according to this invention, by the conventional spin bulb film, MR property spoiled by process annealing by the diffusion and mixing by the interface can keep it good after process annealing.

051] As a modification of the magnetoresistance-effect element of this invention which was mentioned above At least the nonmagnetic interlayer of at least one layer, and the two-layer magnetic layer arranged through the aforementioned nonmagnetic interlayer, In the magnetoresistance-effect element possessing the spin bulb film which has the antiferromagnetism layer which fixes magnetization of at least one layer among the aforementioned magnetic layers, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film The aforementioned antiferromagnetism layer is arranged in contact with the improvement layer in the magnetoresistance effect which has at least the cascade screen of two or more metals, and one side of an alloy layer. And the element with which the element which mainly constitutes the aforementioned improvement layer in the magnetoresistance effect

mainly constitutes the aforementioned antiferromagnetism layer, and the magnetoresistance-effect element for which it does not dissolve are mentioned.

052] At least the two-layer magnetic layer arranged through the nonmagnetic interlayer of at least one layer, and the aforementioned nonmagnetic interlayer as other modifications, In the magnetoresistance-effect element possessing the spin bulb film which has the antiferromagnetism layer which fixes magnetization of at least one layer among the aforementioned magnetic layers, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film The aforementioned antiferromagnetism layer is arranged in contact with the improvement layer in the magnetoresistance effect which has at least the cascade screen of two or more metals, and one side of an alloy layer. And the magnetoresistance-effect element containing at least one sort of elements with which the aforementioned improvement layer in the magnetoresistance effect is chosen from Cu, Au, Ag, Pt, Rh, Ru, aluminum, Ti, Zr, Hf, Pd, and Ir is mentioned.

053] the improvement layer in the magnetoresistance effect in this invention functions effectively also to improvement in the magnetoresistance effect based on control of not only the effect as high MR maintenance when the free layer by the specular reflection film and the stable interface is thin but the film fine structure, and the magnetostriction control which is the magnetosensitive layer which consists of Co system magnetic materials, such as CoFe alloy for example, Cu ground layer -- if independent -- for example, the lattice spacing of a CoFe alloy -- small becoming -- passing -- on the other hand -- Au ground layer -- if independent, the lattice spacing of a CoFe alloy becomes large too much On the other hand, by using a cascade screen and an alloy layer which were mentioned above, Co system magnetic materials, such as Co as a magnetosensitive layer, and a CoFe alloy, into a lattice spacing effective in a low magnetostriction, and let d (111) lattice spacing be the range of 0.2055-0.2085nm. A magnetoresistance-effect property improves also by such magnetostriction control.

054] Furthermore, when aiming at improvement in a property of a spin bulb film, suppression of the atomic diffusion by the grain boundary etc. is effective. In order to suppress the atomic diffusion by the grain boundary, it is desirable to form the grain boundary of a spin bulb film big and rough, and to lower grain boundary density. Moreover, it is desirable that it is the structure which should also be called false single crystal film which is the usual not the grain boundary but so-called sub grain boundary which does not almost have a gap of the orientation within a field though the grain boundary exists. A small angle tilt boundary etc. is mentioned as an example of such a sub grain boundary. Also to formation of such a small angle tilt boundary, the improvement layer in the magnetoresistance effect of this invention is effective, by applying the improvement layer in the magnetoresistance effect which consists of the cascade screen and alloy layer of a metal membrane which was mentioned above, can carry out fcc (111) orientation of the spin bulb film, and can make a gap of the direction of crystal orientation between the crystal grain in a film surface less than 1 degrees. A magnetoresistance-effect property improves also by such crystal grain control of a spin bulb film.

055] The magnetoresistance-effect element of this invention is a thing based on the technology of reducing magnetostrictions, such as a CoFe alloy mentioned above, by the Au-Cu alloy or the Au/Cu cascade screen. With or without the nonmagnetic interlayer of at least one layer In the magnetoresistance-effect element possessing the spin bulb film which has at least the two-layer magnetic layer arranged through the aforementioned nonmagnetic interlayer, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film the above -- fcc (111) orientation of the magnetic layer from which the magnetization direction changes with external magnetic fields among the two-layer magnetic layers even if few is carried out, and it is characterized by d (111) lattice spacing being 0.2055nm or more

056] As for d (111) lattice spacing of a magnetic layer, in the magnetoresistance-effect element mentioned above, it is desirable that it is the range of 0.2055-0.2085nm. Moreover, the magnetic layer from which the magnetization direction changes with external magnetic fields consists of Co or a Co alloy.

057] The magnetoresistance-effect element of this invention mentioned above is used for the magnetic head and the magnetic recording medium of this invention. That is, the magnetic head of this invention is characterized by providing a bottom magnetic-shielding layer, the magnetoresistance-effect element of the above-mentioned this invention formed through the bottom reproduction magnetic gap on the aforementioned bottom magnetic-shielding layer, and the top magnetic-shielding layer formed through the bottom reproduction magnetic gap on the aforementioned magnetoresistance-effect element.

058] The magnetoresistance-effect element of the above-mentioned this invention by which the magnetic head of the replay separate-type of this invention was formed through the bottom reproduction magnetic gap on the bottom magnetic-shielding layer and the aforementioned bottom magnetic-shielding layer, The reproducing head which has the top magnetic-shielding layer formed through the bottom reproduction magnetic gap on the aforementioned magnetoresistance-effect element, It is characterized by providing the recording head which has the aforementioned bottom magnetic-shielding layer, the communalized bottom magnetic pole, the record magnetic gap formed on the

mentioned bottom magnetic pole, and the top magnetic pole prepared on the aforementioned record magnetic gap.

059] The magnetic-head assembly of this invention is characterized by providing the head slider which has the magnetic head of the rec/play separate-type of the above-mentioned this invention, and the arm which has the suspension in which the aforementioned head slider was carried. Moreover, the magnetic recording medium of this invention is characterized by providing the head slider equipped with the magnetic head of the rec/play separate-type of the above-mentioned this invention which reads a signal by the magnetic field which writes a signal in a magnetic-recording medium and the aforementioned magnetic-recording medium by the magnetic field, and is generated from the aforementioned magnetic-recording medium.

060] Embodiments of the Invention] Hereafter, it explains in detail, referring to a drawing about the gestalt of operation of this invention.

Gestalt : thin-film-izing of a free layer of the 1st operation) The gestalt of implementation of invention about "thin-film-izing of a free layer" is explained to the beginning.

061] Before here explains the gestalt of operation of this invention, the technical problem about "thin-film-izing of a free layer" which this invention person has recognized in process in which it results in this operation gestalt is explained in full detail.

062] In a magnetoresistance-effect element, as mentioned above, in addition to the rise of MR rate of change, the large improvement in sensitivity is realizable with thin film-ization (reduction of a  $M_s \cdot t$  product) of a free layer. If it says roughly, an output will increase in inverse proportion to the size of the  $M_s \cdot t$  product of a free layer. However, it became clear about thin-film-izing of a free layer that the following problems arise as a result of examination which this invention person performed uniquely.

063] As the 1st problem, it is mentioned that the bias point design at the time of sense current energization is difficult. If the bias point comes in the center of a portion with the alignment-inclination of a transfer curve when the magnetic field which starts at the time of head operation all carries out a leg, it will be called the optimal bias state. However, if the thickness of a free layer becomes thin, since the inclination of a transfer curve will become steep, it becomes very difficult to have the bias point in the center of the alignment field of a transfer curve. If the bias point becomes bad, and the asymmetry (asymmetry) of a signal will come out or it will become still worse, it becomes impossible to completely take an output level.

064] As the 2nd problem, if a free layer is thinned very much with the conventional technology, MR rate of change will produce the problem which falls sharply. Reduction of MR rate of change brings about the fall of a reproduction output.

065] Drawing 7 is a conceptual diagram for explaining two problems enumerated above. That is, this drawing expresses the transfer curve of the magnetic head which used the magnetoresistance-effect element, and when a free layer is thick, this drawing (b) expresses this drawing (a), respectively, when a free layer is thin. Since the inclination of a transfer curve will become steep ( $H_s$  becomes small) and MR rate of change will decrease if a free layer becomes thin as mentioned above, drawing 7 shows that two problems that  $\Delta V$  becomes small arise.

066] Among the above-mentioned problems, the problem especially about the bias point has not been easily recognized, even if the membrane structure was determined, but it reached to an extreme of design top difficulty. "a gap" which this invention person carried out modeled calculation this time, and was obtained on the result and experience -- an amendment -- the bias point was able to be judged by things The calculation technique of the bias point is described below.

067] The bias point is shifted by various external magnetic fields which join a free layer. This shift can be approximated as the sum of 1. current magnetic field ( $H_{cu}$ ), the static magnetic field ( $H_{pin}$ ) from 2. pin layer, the layer joint magnetic field ( $H_{in}$ ) from the pin layer through 3. spacer, and the disclosure magnetic field ( $H_{hard}$ ) from 4. hard bias film. In the magnetic field of the above 1-4, the hard bias magnetic field of 4. is comparatively small. Then, this invention person inquired wholeheartedly paying attention to the sum of the magnetic field of the above 1-3. The formula of the bias point used this time is shown below.

068]

$$I_p = 50 \times (H_{shift}/H_s) + 50 \quad (1-1)$$

$$I_{shift} = -H_{in} + H_{pin} \cdot H_{cu} \quad (1-2)$$

$$I_s = H_{dfree} + H_k \quad (1-3)$$

$$I_{dfree} = \frac{\pi^2 (M_s \cdot t)_{free}}{h} \quad (1-3-1)$$

$$I_{pin} = \frac{\pi^2 (M_s \cdot t)_{pin}}{h} \quad (1-4)$$

$$I_{cu} = \frac{2\pi C \times I_s}{h} \quad (1-5)$$

$$=(I1 - I3)/(I1 + I2 + I3) (1-5-1)$$

re, b.p. of a formula (1-1) is the bias point [%] observed this time. The rated-bias point is 50%, and if it includes to a margin, it can be called bias point with 40 - 60 usable%. If the bias point shifts from these values, asymmetry (asymmetry) cannot come out, or it will become impossible to completely take an output, in being severer.

069] When asymmetry becomes +10% when the bias point becomes 40%, and the bias point becomes 60%, as for the relation between a bias point value and asymmetry, asymmetry becomes about -10%. As for the rated-bias point in its calculation, 30 - 50% becomes an optimum value not on 40 - 60% but on experience so that it may mention later.

070] Drawing 8 is the graphical representation showing the relation between the bias point value on calculation, and the regenerative-signal wave of a head. At the time of 30 - 50% of bias point value, asymmetry is comparatively small, and shows a good signal wave form at it. If the bias point comes to the place shifted, asymmetry will become large so that drawing 8 may show, and it will become impossible however, to use practically from the range.

071] Hshift is the sum [Oe] of each magnetic field which joins a free layer, as expressed with a formula (1-2). Hs is inclination on a transfer curve, as drawing 7 also showed.

072] Drawing 9 is explanatory drawing showing the relation of each of these magnetic fields.

073] Hdfree is the anti-magnetic field of the free layer in a certain MR height length. h is MR height length [μm]. pin is a pin disclosure magnetic field which joins a free layer from a pin layer. (Ms\*t) free is the product of the total saturation magnetic field Ms of a free layer, and Thickness t, and pin(s) (Ms\*t) are the saturation magnetization of the pin layer (magnetic thickness of the pin layer of the upper and lower sides to the case of synthetic AF difference) of the structure of a pin layer, and the product of thickness.

074] Hcu is a current magnetic field which joins a free layer, and Is is sense current [mA]. The coefficient C in a formula (1-5-1) is the ratio of current diverging which flows in the layer of the upper and lower sides of a free layer.

075] Drawing 10 is a conceptual diagram showing the current diverging I1-I3 which flows each class.

076] In the calculation explained here, since it is easy, neither the influence of the ABS side edge section nor the influence of a shield is taken into consideration. the estimate of the bias point by the calculation which this invention person performed, and an actual head -- \*\* -- if -- it has become clear on experience that the bias point shifts to a way's calculation minus side about about 10% If order plus-or-minus 10% takes the usable bias point into consideration from the place of the rated-bias point, it can be called the point of 30% - 50% of bias point value acquired by calculation good [ however ]. Therefore, at the time of the value of 30% - 50%, it can be judged that the practically good bias point was obtained on the bias point obtained by calculation as shown above.

077] The spin bulb film known concretely below until now is taken for an example, and a trouble is explained in detail using the bias point formula mentioned above.

the example 1 of comparison: It is usually a spin bulb (with no spin-filter-less x synthetic AF).

a5/NiFe2/Co0.5/Cu2/CoFe2/IrMn7/Ta5 (a unit is nm) (1)

the above (1) expresses the laminated structure of a spin bulb, and expresses the element and thickness (nm) which constitute each class. This example of comparison is a film on extension of the conventional technology which made only the free layer thin by the spin bulb film conventionally [ so-called ]. The bias point was calculated in this film composition.

078] In the bias point formula of - (1-1) (1-5) formula mentioned above, the current magnetic field of a formula (1-5) is difficult to ask especially. The reason is that it is difficult to ask for the current diverging ratio C of a formula (1-5-1). In a thin film, the specific resistance of each class is because the resistivity of bulk is remarkable and values differ in response to the influence of crystallinity, a current distribution, etc. Since calculation which as actually as possible \*(ed) it was performed, this invention person was able to ask for the current diverging ratio C with a sufficient precision by performing the following devices this time.

079] In order to ask for the specific resistance of each class, some films changed to order plus-or-minus 2nm were produced, and the thickness of a layer and the relation of conductance which observe were extrapolated in a straight line and it asked for them to produce the spin bulb film of the above-mentioned composition, and ask for the specific resistance of a certain layer. The reason searched for such is that the actually based value does not become by the technique of asking for specific resistance by the monolayer of the thin film used well. In order to make influence of crystalline, and influence of a current distribution as small as possible, it became clear by examination of this invention person that it is most accurate to make it the material as practice even with the same up-and-down film, and to see the conductance difference in a minute thickness range which was mentioned above.

0080] Since not only the influence of crystalline is small, but the specific resistance of each class for which it asked by his technique includes the influence of a current distribution, precision becomes good considerably from the current diverging ratio C of the formula (1-5-1) for which it asked by the simple parallel conductor using the specific resistance of a monolayer. By adoption of this technique, precision is raised more and the conventionally difficult

urrent magnetic field can be expected now also by calculation.

0081] As a result of asking for the specific resistance of each class by the above technique, NiFe is 20micro omegacm. CoFe is 13microomegacm. Spacers Cu are 8microomegacm. IrMn was set to 250microomegacm. Here, since specific resistance was not able to change rapidly by crystallization and the influence of a scaling object was not able to calculate an exact large value about Cap Ta, either, when thickness was thickened about Ta (tantalum) of a ground, it was assumed that it was 100microomegacm. It asked for the current diverging ratio of each class using these values, and the current magnetic field Hcu was calculated by the formula (1-5).

0082] Moreover, 25Oe(s) of an actual measurement were used as a value of Hin. Hpin was calculated by the formula (1-4).

0083] Since height length becomes short with this film composition while pin thickness has been thick, the disclosure magnetic field Hpin which joins a free layer from a pin layer becomes large and much current flows above the free layer bottom, the current magnetic field Hcu which joins a free layer is also large. Therefore, by the big current magnetic field Hcu, thinking as the design technique of the bias point will cancel and carry out bias point adjustment, and it will have big Hpin.

0084] When sense current is set to 4mA, the result of the bias point value calculated using the above-mentioned value is shown in Table 1.

Table 1: Bias point MR height 0.3micrometer obtained by calculation of film of example 1 of comparison 70%0.5 micrometers 61%0.7 micrometers As shown in Table 1 53%, in MR height of 0.3-0.5 micrometers, the bias point is 61 70%, and is exceeded rather than the value considered on calculation to be the optimal bias point value.

0085] Drawing 11 is a conceptual diagram showing the state of the bias point in this example of comparison. That is, when MR height is narrowed, it turns out that the bias point shifts to an anti ferro side (larger side than 50%). In order to mechanically polishing to perform MR height, dispersion will surely come out of it. Dispersion in such MR height shows that the yield becomes very bad. It originates in that this tends to adjust the bias point by the very unstable technique of canceling the big pin disclosure magnetic field Hpin by the big current magnetic field Hcu as expressed to rawing 11 if it says qualitatively.

0086] Moreover, the film of this example of comparison has a still more essential problem besides the bias point. It is that MR rate of change falls, when the ultra-thin free layer made into the object by this invention is adopted. As a fact which this invention person acquired experimentally, if the thickness of a free layer becomes thin, that MR rate of change after process heat treatment deteriorates extremely will pose a big problem. For example, after process heat treatment, it will decrease to MR rate of change being about 11% in as-depo (state [ having as-deposited : deposited ]) with the composition of the example 1 of comparison even in the size of the abbreviation half of 5.6% of MR rate of change, and as-depo. Now, the spin bulb film of high-density correspondence is unrealizable.

0087] furthermore, since all the thickness of each class is becoming thin in this spin bulb film, field resistance of a pin bulb film also becomes a big value about 30ohms, and is not practical from the point of an electrostatic discharge ESD:Electric Static Discharge) It is because it becomes easy to happen the more the more the resistance of ESD is strong, as known well.

0088] The above thing shows that there is simply nothing by practical film by which the film of the example 1 of comparison is adopted as the head for high-density record.

The example 2 of comparison: U.S. Pat. No. 5422591 (with no x synthetic AF with a spin filter)

La5/Cux/NiFe1.5/Cu2.3/NiFe5/FeMn11/Ta5 (a unit is nm) (2)

In order to improve MR in an ultra-thin free layer, the spin bulb film of composition of having carried out the laminating of the high conductive layer to the free layer in the spacer non-magnetic layer and the opposite side is proposed. For example, patent No. 2637360, U.S. Pat. No. 5422591, U.S. Pat. No. 5688605, etc. can be mentioned.

0089] The film of the above (2) is the example of a spin bulb film based on U.S. Pat. No. 5422591. In this spin bulb film, in the spacer Cu of a free layer, since it will become a simple shunt layer by thickening Cu \*\* which touched the opposite side if the mean free path of rise spin is long, MR rate of change goes up by the bird clapper and Cu \*\* is thickened more than a mean free path, it has the inclination to take the peak of MR rate of change by a certain Cu \*\*. If this phenomenon is used, a part of reduction of MR rate of change in the ultra-thin free layer which was one trouble in the example 1 of comparison is improvable.

0090] However, by the spin bulb film of the above (2) based on U.S. Pat. No. 5422591, it has film composition which is called the thermal resistance of the bias point and MR rate of change and which has a problem at two points.

0091] First, about the viewpoint of the bias point, a direct publication or an indirect suggestion are not indicated at all in the specification of U.S. Pat. No. 5422591. And the film of (2) is composition which is not employable with an actual head at all. The reason is explained in full detail below.

0092] The current magnetic field Hcu was first computed using the specific resistance of each class experimentally

100] In order to show that, the bias point in the film of this composition of having asked by calculation is shown in table 3.

101] Table 3: The bias point MR height in film of example of comparison (3) NiFe 5nm NiFe 3nm 0.3micrometer 6% 108% 0.5 micrometers 83% 104% 0.7 micrometers 81% As  $H_{in}$ , the value of 10Oe was used 100% here. It turns out that the bias point has shifted to the plus side by the film of the composition of the example of comparison (3) even when NiFe thickness is 5nm primarily if Table 3 is seen, and the bias point exceeds in a plus side increasingly if free layer NiFe thickness becomes thin with 3nm although it is the composition which cannot say it as a good design.

102] Drawing 13 is a conceptual diagram showing the relation of the determination element of the bias point in this example of comparison. Since only the current magnetic field  $H_{cu}$  has been reduced while  $H_{pin}$  has been large as expressed to this drawing, in the place where the bias point has thin free thickness, it has composition which cannot be taken at all. That is, since the time of the place which added all current magnetic fields  $H_{cu}$ , layer joint magnetic fields  $H_{in}$ , and pin disclosure magnetic fields  $H_{pin}$  becoming zero is a rated-bias point point, even if it is going to bring a current pin center, large close to a free layer like the structure of the above (3) and is going to make only a current magnetic field into zero, it becomes the film design which is completely meaningless.

103] Furthermore, the point that high MR rate of change required for densification cannot be obtained as fault of the end point which the structure of the above (3) has can be mentioned. That is, in the structure of (3), since the material of comparatively high resistance is inserted between the high conductive layer and the free layer as a diffusion prevention layer, when it becomes an ultra-thin free layer, the spin-filter effect of MR which is obtained by the Gurney effect is no longer acquired. MR rate of change will fall by the film of the composition of a free layer which demonstrates power especially by this invention explained in full detail behind of (3) from a field 4.5nm or less.

104] Above, for the reason of two points, the structure of the above (3) is the way of thinking in the field where a free layer is comparatively thick strictly, and it turns out that it does not become practical film composition at all in an ultra-thin free layer.

105] The example 4 of comparison: Spin-filter-less x synthetic

FTa5/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (a unit is nm) (4) In this example of comparison, in order to raise a pin property, synthetic AF structure was adopted. Anti ferro distributor shaft coupling (antiferromagnetism combination) of the two-layer ferromagnetic layer through Ru (ruthenium) is carried out. On the other hand, the ferromagnetic layer of one of these has fixed to \*\* with the antiferromagnetism film. By adoption of synthetic AF structure, with normal pin structure, it becomes possible to use, if there is a certain amount of size on the other hand even when the tropism anisotropy field  $H_{ua}$  is small, and pin thermal resistance improves. Moreover, as already stated, with synthetic AF structure, each other [ layer / ferromagnetic / of the upper and lower sides through Ru ] magnetization direction has turned to the retrose, and since the joint magnetic field is far larger than the medium magnetic field at the time of Number kOe and head operation, as for the magnetization moment which comes out outside, the difference of  $M_s \cdot t$  of an up-and-down pin layer is considered to be the moment of a network in approximation. That is, it becomes possible to make small influence of a \*\*\*\*\* pin disclosure magnetic field at a free layer, and the bird clapper is advantageously expected on the bias point (JP, 7-169026, A).

106] For example, in the case of the example of comparison, it is thought with a 0.5nm pin layer that pin \*\* of a network is equivalent, and a pin disclosure magnetic field equivalent to an unrealizable thin pin layer can be realized with normal pin structure. Ideally, if an up-and-down pin layer is arranged with the same  $M_s \cdot t$  product, a pin disclosure magnetic field will be called zero. Only by reducing such a pin disclosure magnetic field, it was thought that the bias point design of a densification correspondence spin bulb film was enough. However, in the ultra-thin free layer of high-density correspondence, this invention person found out that the bias point stabilized only with synthetic AF structure was unrealizable this time. The content is explained below.

107] Drawing 14 is a conceptual diagram showing the relation of the determination element of the bias point in this example of comparison. That is, in the composition of this example of comparison, since the free layer is located in the place from which it separated greatly from the current pin center, large of the current distribution of a spin bulb film, the current magnetic field  $H_{cu}$  is very large. At most by about 20 Oes, it is in the state where current is not passed at all at the pin disclosure magnetic field is also very small by adoption of synthetic AF structure, and  $H_{in}$  is in the state of bias almost just. If current is passed by the spin bulb film of this composition, the more it passes current, the more it will shift from bias just by the big current magnetic field  $H_{cu}$ .

108] The result of the bias point calculation about this example of comparison is shown in Table 4.

109] Table 4: The bias point MR height obtained by calculation of film of example 4 of comparison  $H_{cu} \cdot H_{pin}$  [  $H_{cu} \cdot H_{pin} \cdot 0.3 \text{micrometer}$  88% 22% 0.5 micrometers 80% 16% 0.7 micrometers 73% The value of 20Oe(s) was used as  $H_{in}$  10% here. Table 4 shows that the bias point cannot realize 30 - 50% of value, whichever it passes current to the sense as expected.

0110] This is not desirable although a pin disclosure magnetic field is made small as much as possible, and it is got locked with this structure as a means to obtain bias just, and is equal in the pin thickness of the upper and lower sides with synthetic AF structure, that is, the technique which it has in bias just by the current magnetic field can be considered so that a pin disclosure magnetic field may be mostly made into zero, and  $H_{in}$  may be enlarged if possible and the big  $H_{in}$  may be canceled. It not only shifts the alignment field of an external-magnetic-field response simply, but big  $H_{in}$  brings about the bad influence which decreases an alignment field. Moreover, it is very difficult to control  $H_{in}$  by the small value uniformly, and it is not desirable that it is going to control by the big value uniformly unnaturally, and is going to produce a spin bulb film although it is good, even if it thinks from the point of mass production method.

0111] Moreover, since there is no high conductive layer in the spacer of a free layer, and the field of an opposite side, at the time of an ultra-thin free layer, MR rate of change deteriorates in the completely same reason as the example 1 of comparison, and output sufficient as a head for high-density record cannot be secured. This is also an essential problem.

0112] As mentioned above, by the spin bulb film by adoption of only synthetic AF structure, it cannot perform realizing the ultra-thin free layer spin bulb film for high-density record at all from two points of the bias point and high power.

0113] As explained in full detail above, by the film of composition [ like the examples 1-4 of comparison ] whose this invention person is, the stable bias point and sufficient high power were clarified by performing the calculation and the trial production of a current magnetic field which were actually based [ that there is a problem that it cannot attain, and ] as a spin bulb film with the ultra-thin free layer for high-density record. And still more original trial production examination is carried out and it came to invent the composition explained in full detail below.

0114] Drawing 15 is the graphical representation expressed comparing the free thickness dependency of the bias point of the spin bulb film of each example of comparison mentioned above, and the spin bulb film by this invention. Any composition is known by that a big problem is in the bias point by the spin bulb film of each example of comparison known so far. Here, the optimal bias point is in 30 - 50% of range. And in order to fully obtain sensitivity, in low  $M_s \cdot t$ , it is necessary to obtain the bias point within the limits of this.

0115] On the other hand,  $M_s \cdot t$  has all separated from each example of comparison greatly from the range with the optimal bias point in low conditions. Furthermore, it turns out that the change of the bias point to  $M_s \cdot t$  is very large, and regulation of the bias point is difficult.

0116] On the other hand, the example 1 of this invention explained in full detail behind has the very small change of the bias point to  $M_s \cdot t$ , and it turns out that there is the bias point within the always optimal limits.

0117] In drawing 15, although the bias point on calculation has not said [  $M_s \cdot t$  ] 30% - 50% of range about the example 1 of comparison even place [ of 5 or more nmTs / big ], this is because it is a value with larger MR height length in low recording density for which  $M_s \cdot t$  uses the free layer of 5 or more nmTs in fact. It is because it is specifically a larger value than 0.3 micrometers - 0.5 micrometers of MR height length in the target recording density of this invention.

0118] Anyway, in the place where  $M_s \cdot t$  is the field of 5 or less nmTs, the dominance difference of a bias point design of the film of this invention and the film of the example of comparison is large, and a bird clapper is known clearly.

0119] In the structure of the examples 1-4 of comparison mentioned above, drawing 16 is a graphical representation showing how MR rate of change changes, when only  $M_s \cdot t$  of a free layer is made small. Here, MR rate of change of a vertical axis is an amount mostly proportional to the vertical axis of the transfer curve of drawing 9. The film of the examples 1 and 2 of this invention explained later was also shown for comparison.

0120] Here,  $M_s \cdot t$  of the film of the examples 1-4 of comparison and the film of the example 1 of this invention manufactured the sample which changed the NiFe thickness of a free layer, and the film of an example 2 created what changed the thickness of CoFe of a free layer. All of these values are the results after performing process annealing of 0 hours at 270 degrees C all over the magnetic field of 7kOe(s).

0121] Moreover, the high conductive layer of the example 2 of comparison and examples 1 and 2 was taken as Cu of nm of thickness. As  $M_s \cdot t$  of a free layer, the arrow showed the thing of the thickness of the free layer of the example of comparison all over this drawing. Moreover, as  $M_s \cdot t$  of a free layer,  $M_s$  of NiFe set to 1.8T and showed  $M_s$  of 1T and CoFe by the thickness of NiFe conversion of 1T altogether.

0122] By the film of the examples 1, 3, and 4 of comparison which do not have the high conductive layer which touches a free layer, if  $M_s \cdot t$  of a free layer becomes small, MR rate of change will deteriorate rapidly and it will become difficult to secure the high power dealing with densification.

0123] The thermal resistance of MR rate of change [ as opposed to / although the free layer  $M_s \cdot t$  dependency of MR rate of change is comparatively small, since FeMn which does not contain noble metals in an antiferromagnetism film

; used by the film of the example 2 of comparison which has a high conductive layer / process heat treatment ] is a low. In such small MR rate of change, high power of densification is not securable.

0124] If 0.5nm Co or CoFe is inserted between Spacer Cu and the free layer NiFe, although it will become larger about 1 to 2% than the value in this drawing by the film of the example 2 of comparison, and the example 3 of comparison, the dependency over  $Ms \cdot t$  does not change with the case of the free layer of a NiFe monolayer, but is enough as MR rate of change in the place where  $Ms \cdot t$  of a free layer is small anyway. [ of a small value ]

0125] If the free layer which, on the other hand, has the high conductive layer which touched the free layer by this invention, and the antiferromagnetism film which has noble metals are used, the thermal resistance of MR rate of change to process heat treatment can also be improved, and sufficient high power of high-density correspondence can be obtained. The difference of MR rate of change with the example of comparison is large, and a bird clapper is known in the place which became smaller than 5nmT especially.

0126] Below, the magnetoresistance-effect element of this invention is explained in detail.

0127] Drawing 1 is a conceptual diagram showing the cross-section composition of the magnetoresistance-effect element of this invention. That is, the magnetoresistance-effect element of this invention has the composition which carried out the laminating of the high conductive layer 101, the free layer 102, the spacer layer 103, the 1st ferromagnetic layer 104, the joint film 105, the 2nd ferromagnetic layer 106, and the antiferromagnetism film 107.

0128] The good bias point is realizable by realizing  $H_{pin} - H_{in} = H_{cu}$  by making  $H_{cu}(s)$ ,  $H_{pin}(s)$ , and all the  $H_{in}(s)$  into small value by this composition, when  $H_s$  on the transfer curve by having thinned the free layer 102 very much specially is small. Furthermore, the head of high power is realizable by maintaining the thermal resistance of good MR rate of change for generally it being hard coming to realize high MR rate of change in the case of an ultra-thin free layer.

0129] That is, by spin bulb film composition of this invention, since the good bias point can be realized and high MR rate of change can be maintained even when it has an ultra-thin free layer for high-density, it is stabilized and high power can be obtained. Specifically, the good bias point is realizable by realizing  $H_{pin} - H_{in} = H_{cu}$  as a bias point design. It is important that  $H_{pin}(s)$ , and all  $H_{in}(s)$  and  $H_{cu}(s)$  make it small, in order to be stabilized and to realize the upper formula.

0130] First, by using the so-called synthetic AF structure which the 2nd ferromagnetic of the above combined in antiferromagnetism to  $H_{pin}$ , actually acting as  $H_{pin}$  becomes only what is depended on the difference of the two-layer magnetic thickness of the above 1st and the 2nd ferromagnetic, and it can reduce  $H_{pin}$ .

0131] It turns out that it is effective to reduce pin ( $Ms \cdot t$ ) of a pin layer because of  $H_{pin}$  reduction even if this sees a formula (1-4).

0132] However, it is indispensable for it to be completely meaningless, even if it reduces only  $H_{pin}$  for the bias point design of an ultra-thin free layer, and to also reduce the current magnetic field  $H_{cu}$ . Therefore, by making the field of opposite side carry out a nonmagnetic quantity conductive layer in contact with the spacer of a free layer, the center of the current distribution of current of flowing the inside of a spin bulb film can be brought close to a free layer, and it becomes possible to reduce  $H_{cu}$ . That is, in a formula (1-5) and a formula (1-5-1), when  $I_3$  increases at the time of a top type spin bulb film ( $I_1$  increases when it is a bottom type spin bulb film) and the current diverging ratio  $C$  falls, it is because the current magnetic field  $H_{cu}$  is suppressed. It is in high MR rate of change being maintainable as another big work of a nonmagnetic quantity conductive layer with the spin-filter effect at the time of the ultra-thin free layer made into the object by this invention. That is, the magnetization direction of the pin layer of the side which touches a free layer and a spacer can keep large mutually the difference of the mean free path of rise spin in the time of an parallel state and an anti-parallel state by preparing a nonmagnetic quantity conductive layer.

0133]  $H_{pin} - H_{in} = H_{cu}$  It is stabilized, and  $H_{in}$  reduction is also important in order to realize. Although it is important to make spacer \*\* thin for the high MR rate-of-change realization (the spin-filter effect) by the high conductive layer which touched the above ultra-thin free layers, generally  $H_{in}$  tends to become large, so that spacer \*\* becomes thin, and, so that a free layer becomes thin. It is important to conquer it and to use this invention by  $H_{in}$  of the range of about 0-20 Oes.

0134] Drawing 2 is the schematic diagram of the transfer curve obtained in the spin bulb film of this invention. Also in a transfer curve with small  $H_s$  using the ultra-thin free layer, since  $H_{pin}(s)$ , and all  $H_{cu}(s)$  and  $H_{in}(s)$  are reduced, the design of  $H_{pin} - H_{in} = H_{cu}$  is attained and the bias point has set it as about 50% of good place. Furthermore, since the spin-filter effect by the high conductive layer is also used, high MR rate of change can be maintained also in an ultra-thin free layer, and the vertical axis of drawing 2 has also realized the sufficiently large value.

0135] Next, each parameter of each element which determines the bias point, i.e.,  $H_{pin}$ , and  $H_{in}$  and  $H_{cu}$  is further explained to a detail.

0136] First, low  $H_{cu}$  is explained. As already explained, in this invention, by preparing a high conductive layer in the

de which touches the field of an opposite side, the value of C in a formula (1-5) is reduced, and the current magnetic field Hcu is reduced with the spacer of a free layer. It explains using the following film composition as a concrete example.

[137]

5/Cu<sub>x</sub>/CoFe<sub>2</sub>/Cu<sub>2</sub>/CoFe<sub>2.5</sub>/Ru<sub>0.9</sub>/CoFe<sub>2</sub>/IrMn<sub>7</sub>/Ta<sub>5</sub> (a unit is nm)

Drawing 3 is a graphical representation to which the spacer which is in contact with the free layer expresses the relation of the current magnetic field Hcu which joins the free layer to the thickness of the high conductive layer Cu of an opposite side in the above-mentioned film. Here, sense current was set to 4mA. The value of C of a formula (1-5) is small, and the current magnetic field Hcu is reduced by the bird clapper, so that the thickness of Cu is made to increase as shown in this drawing. When the current diverging ratio by the side of the upper layer and a lower layer becomes equal rather than a free layer, however the current magnetic field which joins a free layer may pass sense current, it turns into a zero magnetic field.

[138] Here, as for the thing of the point of this invention for which the current magnetic field Hcu is completely made into zero, it is not [ one ] conversely desirable but to reduce the current magnetic field. It sets to this invention and is  $\mu_{\text{pin-Hin}} = H_{\text{cu}}$ . It is because bias point adjustment becomes impossible like the example 3 of comparison mentioned above by the design which is going to carry out near of the current magnetic field to zero since bias point adjustment is performed by making it realized.

[139] When the thickness of a nonmagnetic quantity conductive-layer Cu layer is said in the big range, considering the viewpoint of a current magnetic field, within the limits of 0.5nm - 4nm will call it proper thickness. Since Hs becomes small so that the thickness of a free layer becomes thin, the one where the current magnetic field Hcu is also smaller becomes desirable. Here, as a nonmagnetic quantity conductive layer, although Cu was used, when using other metallic materials or a cascade screen, it can think by the thickness altogether converted into Cu. since the specific resistance for which it asked experimentally in the case of a nonmagnetic quantity conductive layer called Ru 1.5 m/Cu 1nm is [ 30microomegacm and Cu of Ru ] 10microomegacm -- Cu conversion -- (1.5nm x 10microomegacm / 0microomegacm) -- it will be said that it is equivalent to Cu thickness of +1nm = 1.5nm

[140] as the specific resistance for which it asked experimentally when other metals were used similarly -- Cu -- 0microomegacm and Ir can use 20microomegacm, as for 30microomegacm and Au, Re can use the value to which in 0microomegacm and Pt 40microomegacm and aluminum say 12microomegacm to and 40microomegacm and Pd say 70microomegacm and Rh ] Os as 30microomegacm, and, as for 10microomegacm and Ag, 10microomegacm and Ru can ask for a current diverging ratio Moreover, when a nonmagnetic quantity conductive layer consists of an alloy, using the value of the above-mentioned specific resistance of the element of the principal component, it can calculate its thickness of Cu conversion and you may distribute proportionally according to composition of an element.

[141] Although the value of this specific resistance changes by the adjoining material as the example of comparison was explained, since the material which a nonmagnetic quantity conductive layer touches does not differ greatly, the value calculated using these values can prescribe proper thickness.

[142] Moreover, since Hcu is decided by the current diverging ratio of the upper layer and a lower layer to a free layer so that it may understand by the formula (1-5), a nonmagnetic quantity conductive layer has the thinner possible one desirable [ the thickness of a spacer layer located in a reverse side ] from a viewpoint of Hcu reduction. This [ the inclination's demanded from the spin-filter effect of MR rate of change of next explanation ] corresponds. Specifically, spacer thickness has 1.5nm - desirable about 2.5nm.

[143] The nonmagnetic quantity conductive layer has also achieved the function as a layer to bring about the spin-filter effect of MR rate of change with current magnetic field Hcu reduction. It originates in the effect and the range of its thickness is also limited to some extent. For example, since considering the conduction electron which moves to the free layer side from a pin side it becomes desirable composition that a mean free path difference becomes [ the magnetization direction of a free layer ] large by parallel or anti-parallel at a pin layer, the thickness of the spacer independent of the rise of spin and a down has the thinner desirable one. When it will be called the thickness which is the grade to which H<sub>in</sub> does not increase, spacer \*\* has 1.5nm - desirable about 2.5nm.

[144] Moreover, free thickness is thick and its one sufficiently thinner than the mean free path of rise spin is more desirable than the mean free path of down spin. For example, since it is about 1.1nm, as thickness of NiFe, when it is CoFe, 1nm - about 3nm is the most desirable [ the mean free path of the down spin of NiFe / 1nm - its about 4.5nm is the most desirable, and ]. Although the optimal thickness changes with pin \*\*, spacer \*\*, and free thickness in high electric conduction thickness, the peak of the thickness of the high electric conduction thickness which takes the peak of MR is carried out to the thick-film side, so that free thickness is so thin that spacer \*\* is thin. for example, a pin layer -- CoFe<sub>2.5</sub>nm and Cu spacer -- thick -- free 2nm -- the case where Cu is used for a high conductive layer when it is thickness CoFe<sub>2</sub>nm -- about 2nm, by the way, a peak is taken Since the peak of MR rate of change is taken when the

thickness of a free-on experience layer and the total thickness of the nonmagnetic quantity conductive layer Cu are set about 4-5nm, it is desirable to set up the thickness of a nonmagnetic quantity conductive layer so that it may become near. When Cu is used for the nonmagnetic quantity conductive layer which touches a free layer, the total thickness of Cu thickness and free layer thickness serves as a range with 3nm - desirable about 5.5nm also including a margin.

[145] Next,  $H_{pin}$  is explained. efficiency pin  $**$  [ in CoFe whose  $B_s$  is 1.8T ] in order to reduce  $H_{pin}$  -- about 2nm or less (it is 3.6nm or less by NiFe conversion), and a still more desirable efficiency-pin -- thick -- it is desirable to make 1nm or less (for it to be 1.8nm or less by NiFe conversion) As a realization means of the pin layer, synthetic AF structure is desirable. This consists of composition of an antiferromagnetism film / 1/Ru0.9nm of ferromagnetics / ferromagnetic 2, and is carrying out magnetic coupling of a ferromagnetic 1 and the ferromagnetic 2 in antiferromagnetism. While joined together in antiferromagnetism and, on the other hand, magnetization fixing of the ferromagnetic 1 is carried out with the antiferromagnetism film at  $**$ . the magnetization direction of a ferromagnetic 1 and a ferromagnetic 2 -- a retrose -- the joint magnetic field -- several -- kOe and since it is large, the difference of  $I_s*t$  of a ferromagnetic 1 and  $M_s*t$  of a ferromagnetic 2 is considered to contribute to an efficiency pin disclosure magnetic field as primary approximation (JP,7-169026,A)

[146] For example, with composition called IrMn/CoFe2/Ru0.9/CoFe2.5 (the unit of thickness is nm), efficiency pin  $*$  will call it 2.5nm-2nm=0.5nm (magnetic thickness is 0.9nmT(s)). If efficiency pin thickness can be reduced,  $H_{pin}$  can be reduced as shown in a formula (1-4). Thus, synthetic AF structure is structure indispensable for mastering an ultra-thin free layer in respect of the bias point of this invention.

[147] Next,  $H_{in}$  is explained. When said from the point of the bias point and the spin-filter effect, it was already said that it is desirable to make it as thin as possible as for Cu layer thickness used as a spacer. As a concrete value of  $H_{in}$  in such thin thickness, it is desirable to hold down to about 5-15 Oes still more desirably zero to 20 Oe. As the one solution method of this invention, even when a spacer is thin, bilayer ground composition etc. is raised as film composition which does not increase  $H_{in}$ .

[148] Next, the thermal resistance of MR rate of change is explained. When an ultra-thin free layer is used, it also becomes remarkably difficult to maintain the thermal resistance to process heat treatment of MR rate of change. Specifically, in order to improve MR rate-of-change thermal resistance of an ultra-thin free layer spin bulb film, it divides greatly and there are two measures. It is preparing the nonmagnetic quantity conductive layer more than [ with one of them ] fixed in contact with a free layer. Although the nonmagnetic quantity conductive layer, of course, also had a role of a spin-filter effect, it became clear to also play the role of raising the thermal resistance of MR rate of change. Although the thickness of a free layer was not so remarkable, when, as for this, it became thin by about 4.5nm to about 2nm, 1nm or more was understood are indispensable as total thickness of a nonmagnetic quantity conductive layer. For example, although it will decrease about 50% by the relative ratio at MR rate of change of as-depo, and MR rate of change after process heat treatment (270 degree-Cx 10 hours) when a nonmagnetic quantity conductive layer is nm, it can hold down to 0 - 30% of reduction by preparing an about 1nm nonmagnetic quantity conductive layer.

[149] Furthermore, dispersion is still in the rate of heat deterioration of MR rate of change only now. This cause is the difference of the antiferromagnetism film material which is the 2nd measure. As an antiferromagnetism film, the time of using FeMn etc. is the case of the 30% of the above-mentioned rates of heat deterioration. However, when using IrMn as an antiferromagnetism film material, it can be made to decrease to 0 - 15% of rate of degradation. Furthermore, although MR rate of change of as-depo cannot be measured when using PtMn, it is realizable in general, % of values of heat deterioration, i.e., the rate, of MR rate of change of IrMn. [ of as-depo ] This was dependent on whether the noble-metals concentration of antiferromagnetism film material is included, and the desirable thing made it clear especially on the spin bulb film of an ultra-thin free layer according [ using the antiferromagnetism film containing noble metals like IrMn, PtMn, PdPtMn, and RuRhMn ] to this invention.

[150] Drawing 4 is a graphical representation showing the concrete range of the pin thickness of synthetic AF for getting asymmetry blocked and realizing bias point 30%-50% -10% to +10%, as the above conclusion, and nonmagnetic quantity electric conduction thickness. Here, it is defined as  $(V1-V2)/(V1+V2)$  with "asymmetry, i.e., wave asymmetry", with the absolute value V1 of the reproduction output in a right signal magnetic field, and the absolute value V2 of the reproduction output in a negative signal magnetic field. Therefore, it corresponds to asymmetry is -10% - +10%" being " $(V1-V2)$  the value of /  $(V1+V2)$  is 0.1 or less 0.1 or more minus plus."

[151]  $H_{pin}-H_{in}=H_{cu}$  In order to realize, you also have to lower  $H_{cu}$ , when  $H_{pin}$  becomes small. That is, as shown in formula (1-4) and (1-5), it is the pin thickness ( $M_s*t$ ) (when pin is made small, thickness of a nonmagnetic quantity conductive layer must be thickened and pin ( $M_s*t$ ) is made into a larger value, you have to make thickness of a nonmagnetic quantity conductive layer thin.) of the upper and lower sides of synthetic AF.

[152] Specifically, when thickness of  $t_m$  (pin2) and a nonmagnetic quantity conductive layer is set to  $t$  (HCL) (it converted into Cu layer of specific resistance 10microomegacm) for the thickness of  $t_m$  (pin1) and a thin pin layer, the

ickness of the thick pin layer which forms synthetic AF. The place with which are satisfied of  $0.5 \text{ nm} \leq t(\text{pin1}) - t(\text{pin2}) + t(\text{HCL}) \leq 4 \text{ nm}$  and  $t(\text{HCL}) \geq 0.5 \text{ nm}$  is the range of this invention.  $0.5 \text{ nm} \leq t(\text{pin1}) - t(\text{pin2}) + t(\text{HCL})$  is the limitation that the bias point becomes about 30% that is, and asymmetry becomes +10% here, and  $t(\text{pin1}) - t(\text{pin2}) + t(\text{HCL}) \leq 4 \text{ nm}$  is the limitation that the bias point becomes about 50% that is, and asymmetry becomes -10%.

[153] Here,  $t(\text{pin1}) - t(\text{pin2})$  is the magnetic thickness when converting into NiFe whose  $M_s$  is 1T, for example, it will be called  $x(2.5-2)1.8T=0.9 \text{ nm}$  at the time of the synthetic AF structure of the composition of PtMn/CoFe<sub>2</sub>/Ru<sub>0.9</sub>/CoFe<sub>2.5</sub>. Moreover, in the case of the monolayer pin structure of the example of comparison shown for comparison,  $(M_s \cdot t)$  of a monolayer pin layer is used.

[154] Moreover,  $t(\text{HCL})$  is the case where a nonmagnetic quantity conductive layer is made into the thickness of Cu conversion, and when using nonmagnetic quantity conductive layers other than Cu, it can be made into the thickness of Cu conversion using the resistivity mentioned above.

[155] Moreover,  $t(\text{HCL}) \geq 0.5 \text{ nm}$  of lower limits of the thickness of a nonmagnetic quantity conductive layer required for high MR realization in a free layer thinner than 4.5nm is specified. Moreover, if the thickness of a nonmagnetic quantity conductive layer is set to 3nm or more, since  $\Delta R_s$  may fall as a still more desirable range of the above-mentioned range,  $t(\text{HCL}) \leq 3 \text{ nm}$  is desirable. Moreover, if the difference of the vertical pin thickness of synthetic AF is set to 3nm or more, since the thermal resistance of magnetization fixing of a pin layer will deteriorate, is desirable that it is  $t(\text{pin1}) - t(\text{pin2}) \leq 3 \text{ nm}$ .

[156] In drawing 4, the data of the film of the examples 1-4 of comparison mentioned above and the example 1 of this invention explained in full detail behind were plotted. Here, in the case of synthetic AF structure, the pin layer by the side of a spacer layer turned on the magnetic thickness of pin layer of horizontal axis plus-side, when magnetic thickness was thicker than another pin layer, and the pin layer by the side of a spacer layer decided to take the magnetic thickness of the pin layer of a horizontal axis to a minus side, when magnetic thickness was thinner than another pin layer. It decided to take all the magnetic thickness of a pin layer at a plus side in the case of the conventional pin layer which does not use synthetic AF.

[157] As shown in this drawing, although it separates from all the examples of comparison from the good range and asymmetry is bias bad, that is, large, according to this invention, the good bias point, i.e., a film with small asymmetry, is realizable.

[158] The concrete film composition which conquered the heat-resistant difficult point of the bias point design by this invention explained above which cancels small  $H_{\text{pin}}$  by synthetic AF by small  $H_{\text{Cu}}$ , that is, realizes  $H_{\text{pin}} - H_{\text{in}} = H_{\text{Cu}}$ , and MR rate of change peculiar to an ultra-thin free layer spin bulb film is shown.

Example 1) Top SFSV (NiFe/Co(Fe) free layer)

a<sub>5</sub>/Cu<sub>x</sub>/NiFe<sub>2</sub>/CoFe<sub>0.5</sub>/Cu<sub>2</sub>/CoFe<sub>(2+y)</sub>/Ru<sub>0.9</sub>/CoFe<sub>2</sub>/IrMn<sub>7</sub>/Ta<sub>5</sub> (7-1) An antiferromagnetism film first explains the example of the so-called top type located in an upper layer side rather than a free layer of spin bulb film.

[159] Drawing 5 is the conceptual diagram showing the concrete film composition of the magnetoresistance-effect element of this example. That is, the laminating of the free layer 102 and the spacer layer 103\*\* was carried out the characteristic high conductive layer 101 by this invention, and on it on the ground buffer layer 12, the ferromagnetic in layer 104, 106 joined together in antiferromagnetism through 105, and, on the other hand, the pin layer of 106 has fixed to \*\* by the antiferromagnetism layer 107. The cap layer 113 is formed on the antiferromagnetism layer 107. The membrane structure of (7-1) is the thing of the type with which the free layer 102 consists of a cascade screen of the layer of 110 and 111, and the nonmagnetic quantity conductive layer 101 consists of a monolayer Cu.

[160] The film of (7-1) turns into a film which was compatible in MR and the bias point using the spin-filter effect of IR by Cu ground, the current magnetic field  $H_{\text{Cu}}$  reduction effect, and the  $H_{\text{pin}}$  reduction effect by synthetic AF. The result which calculated the bias point by the method mentioned above is shown in Table 5 about this film.

[161] Table 5 Bias point calculation result (a)  $y = 0.5$   $H_{\text{in}} = 20 \text{ Oe}$  MR height  $x = 20.3 \text{ micrometers}$  37% 0.5 micrometers 1% 0.7 micrometers 25% (b)  $y = 0.8$   $H_{\text{in}} = 20 \text{ Oe}$  MR height  $x = 20.3 \text{ micrometers}$  46% 0.5 micrometers 40% 0.7 micrometers 33% (c)  $y = 0.5$   $H_{\text{in}} = 10 \text{ Oe}$  MR height  $x = 20.3 \text{ micrometer}$  42% 0.5 micrometers 39% 0.7 micrometers Ground Cu \*\* could be 2nm 36% here. At the time of Cu ground of the monolayer which consists of a high conductive layer of a simple monolayer,  $H_{\text{in}}$  serves as 20Oe(s) and a larger value a little. Then, the result of Table 5 (a) shows that the pin thick difference of synthetic AF shifts to a minus side a little from 40% of a good bias point value in 0.5nm. Although it is a film also with this sufficiently practical, the case where  $y = 0.8 \text{ nm}$  and  $H_{\text{pin}}$  are increased a little is as a result of Table 5 (b). This enables it to bring the bias point close to a good value, when the bias point has shifted with some undershirt, as shown in Table 5 (a). Moreover, as shown in Table 5 (c), even if it lowers  $H_{\text{in}}$ , the bias point can be similarly made into a good value. Since the one where  $H_{\text{in}}$  is smaller will become [ the height dependency of the bias point ] small so that clearly if (c) is compared with Table 5 (a) and (b), as for  $H_{\text{in}}$ , decreasing as much as possible is desirable. Although  $H_{\text{pin}}$  becomes [ the smaller one ] small and a height dependency becomes small, the vertical pin

ick difference of synthetic AF structure With the about 0.3nm difference of (a) and (b), since it is almost influential  $y = 0 - 1\text{nm}$  ( $M_s \cdot t = 0 - 1.8\text{nmT}$  in NiFe) is desirable still more desirable, and the range of  $y = 0 - 0.5\text{nm}$  ( $0 - 9\text{nmT}$  in NiFe) with the bias point The improvement in a property of the cure against ESD-proof etc. is taken into consideration, and since adjustment of the value of  $y$  is possible, it is desirable.

[162] Ground Cu \*\* also uses the spin-filter effect of MR with bias point adjustment. although  $H_{cu}$  will become small if ground Cu \*\* is thickened, in order that  $\Delta R_s$  may decrease -- Cu -- thick --  $0.5 - 3\text{nm}$  is especially desirably desirable  $0.5\text{nm} - 5\text{nm}$  the optimal thickness of the Shimoji Cu \*\* from which, as for ground Cu \*\* from which the spin-filter effect of MR is acquired, the spin-filter effect of MR is acquired for the time when free thickness is thinner depending on free lamination is shifted to the thicker one In the result obtained experimentally, when the sum of ground Cu \*\* and the thickness of a magnetic free layer is  $4\text{nm} - 5\text{nm}$ , MR rate of change takes peak value.

[163] In the case of free lamination as shown in (7-1), the effect of  $R_s$  reduction by the increase in MR by the spin-filter effect according [ ground Cu \*\* ] to Cu thick increase and Cu thick increase cancels  $0 - 1.5\text{nm}$  exactly, and  $\Delta R_s$  does not almost have change in it. 1.  $\Delta R_s$  will decrease in  $5\text{nm} - 2\text{nm}$ , and  $\Delta R_s$  will decrease by  $0.25\text{ohms}$  in about  $0.1\text{ohms}$  and  $1.5\text{nm} - 3\text{nm}$ . Since the fall of  $\Delta R_s$  is proportional to loss of power mostly as it is, it is not desirable. however -- case it is desirable for ground Cu \*\* to thicken on the bias point -- this free lamination -- Ground Cu -- thick -- using  $3\text{nm}$  is also considered At this time, the current magnetic field per unit current is small, and since the spin bulb membrane resistance is also falling, it can consider the technique of recovering the loss of power by the fall of  $\Delta R_s$  by passing more current. It is because the amount of outputs is also proportional to the amount of current mostly. Since it increases 25% by setting for example, sense current to  $5\text{mA}$  from  $4\text{mA}$  of old calculation when  $\Delta R_s$  falls 10% by increasing ground Cu \*\*, 10 minutes is suppliable with the part of  $\Delta R_s$  fall.

[164] When free thickness is thick NiFe<sub>4</sub>/CoFe<sub>0.5</sub> (nm), ground Cu \*\* has desirable about  $0.5 - 2\text{nm}$ , and when a free layer is thin NiFe<sub>1</sub>/CoFe<sub>0.5</sub>nm, ground Cu \*\* has desirable about  $1 - 4\text{nm}$ . Moreover, you may change the thickness of interface CoFe in  $0.3 - 1.5\text{nm}$ . Moreover, you may use Co or other Co alloys instead of CoFe. Since a soft magnetism cannot be realized in Co simple substance when using Co instead of CoFe, it is desirable to make it as thin as possible.

[165] For example, when NiFe is  $4\text{nm}$ ,  $0 - 1\text{nm}$  and NiFe are  $2\text{nm}$  and  $0 - 0.5\text{nm}$  and NiFe are  $1\text{nm}$ ,  $0 - 0.3\text{nm}$  of Co is desirable. Moreover, when caring about interface diffusion with Ground Cu, you may insert Cu, and Co and CoFe of material [ \*\*\*\* / un- ] also into an interface with Ground Cu. For example, free layers, such as Co<sub>0.3</sub>/NiFe<sub>2</sub>/Co  $0.5$  and CoFe<sub>0.5</sub>/NiFe<sub>2</sub>/CoFe<sub>0.5</sub>, can be considered.

[166] Moreover, you may use the alloy free layer of NiFeCo instead of making it the cascade screen of such an ultra-thin magnetic film.

[167] Moreover, in an ultra-thin free layer which is being made into the object by this invention, it also becomes difficult to realize a low magnetostriction. As one difficult point, the magnetostriction of NiFe is just large and a birdapper is mentioned, so that the thickness of NiFe becomes thin. although nickel<sub>80</sub>Fe<sub>20</sub> (at%) is usually sufficient as composition of NiFe in a free layer called NiFe<sub>8</sub> nm/CoFe<sub>1</sub>nm in order to conquer it -- the case of the free layer of  $4.5$  or less nmTs of this invention -- nickel<sub>80</sub>Fe<sub>20</sub> -- nickel -- it is desirable to make it rich the time of NiFe thickness being specifically about  $4\text{nm}$  -- nickel<sub>81</sub>Fe<sub>19</sub> (at%) -- nickel -- the time of NiFe thickness being about  $3\text{nm}$  richly -- nickel<sub>81.5</sub>Fe<sub>18.5</sub> (at%) -- nickel -- it is desirable to make it rich As an upper limit of nickel concentration, nickel<sub>90</sub>Fe<sub>10</sub> (at%) grade is desirable.

[168] As mentioned above, it is two big purposes the purpose of Ground Cu reducing the current magnetic field  $H_{cu}$ , and realizing the good bias point also in an ultra-thin free layer, and to use the spin-filter effect without degradation of MR rate of change also in an ultra-thin free layer.

[169] If it says from the point of the bias point,  $y$  and  $x$  are not independently decided by the film of the above (7-1), and it will be cautious of a mutual value and it will be decided that it will be it. For example, since the current magnetic field  $H_{cu}$  which cancels it since  $H_{pin}$  will become small if  $y$  becomes small also has the smaller good one, the optimum point shifts the value of  $x$  to the way of a larger value.

[170] Specifically, the following thickness designs can be considered as one example. When pin layers are  $2\text{nmT(s)}$ , as a design in case a nonmagnetic quantity conductive layer is a Cu layer, Cu layer  $0.5 - 1.5\text{nm}$ , When pin layers are  $0.5\text{nmT(s)}$ ,  $1 - 2\text{nm}$  and the pin layer of Cu layer are  $1\text{nmT(s)}$ ,  $1.5 - 2.5\text{nm}$  and the pin layers of Cu layer are  $0.5\text{nmT(s)}$ , and  $2 - 3\text{nm}$  and the pin layer of Cu layer are  $0\text{nmT(s)}$ , Cu layer will be called  $2.5 - 3.5\text{nm}$ .

[171] When a pin layer is Co or CoFe here, the thickness of a pin layer is  $t = (M_s \cdot t)_{pin} / 1.8T$ . When [nm] and a pin layer are NiFe(s), pin layer thickness is  $t = (M_s \cdot t)_{pin} / 1T$ . It will be called [nm].

[172] Spacer Cu may use the alloy containing Au, Ag, or these elements other than Cu etc. However, Cu is the most desirable. The realizing-high MR and ground side of a free layer has [ spacer thickness ] the thinner possible desirable one, in order to make the shunt layer of an opposite side as small as possible and to reduce a current magnetic field. However, since the ferro-magnetic coupling of a pin layer and a free layer will become strong and  $H_{in}$  increase will

ise if too not much thin, about 1.8-2.3nm is desirable still more desirably 1.5nm - 2.5nm.

173] Although the ground quantity conductive layer which has played the big role for the spin-filter effect and current magnetic field reduction consists of Cu(s) of a monolayer here, you may form it by the cascade screen. For a certain reason, in a topspin bulb film, the role of the seed layer of fcc also has fcc or a hcp metallic material good at its time as furring. Specifically, the alloy layer of the metal which consists of Au, Ag, aluminum, Zr, Ru, Rh, Re, Ir, etc., or a cascade screen can be considered. although an effect is enough acquired with simple Cu ground if it is for the spin-filter effect of MR, and the current magnetic field reduction effect, there is a role which is two called magnetostriiction control and  $H_{in}$  control of an ultra-thin free layer as an effect which makes furring an alloy layer and cascade screen purposely. Specifically, the following examples can be considered.

174] Ta5 / Ru1/Cu1.5 / NiFe2/CoFe0.5 / Cu2/CoFe2.5 / Ru0.9/CoFe2 / IrMn7/Ta5 (7-2) By using Ru1nm as a ground, membranous flat nature can improve and  $M_s \cdot t$  of a free layer can realize low  $H_{in}$  of about 10 Oes easily by spacer 2nm in spite of NiFe conversion 2.9nmT and an ultra-thin free layer. Realization of low  $H_{in}$  is desirable at the point as for which MR height dependency of the bias point becomes empty of being lost. Moreover, even if it does not have the thickness difference of the vertical pin layer of synthetic AF in vain, it is desirable also at the point that the good bias point is realizable. Although the thickness of Ru set to 1nm here, 1nm - about 3nm is desirable still more desirably 0.5nm - 5nm. The thickness with desirable material other than Ru does not change so much.

175] By the film of (7-2), when calculating  $H_{cu}$ , it becomes addition of the electric shunt layer of the thickness of Ru and the thickness of Cu. the case of Ru -- the ratio of 30microomegacm and Cu -- in the viewpoint of eye an about 3 me hatchet of specific resistance, and  $H_{cu}$ , the film of (7-2) will say that it is equivalent to a 1.8nm film by Cu thick conversion. However, in the viewpoint of MR, resistance is high in Ru, and most spin-filter effects are not acquired in touching NiFe direct and setting Ru to it, since the electronic mean free path is short. Therefore, as a layer which touches a free layer, Cu, Au, Ag, etc. of low resistance are desirable as much as possible, and material, such as Ru, is reasons with desirable making it a bilayer through Cu, Au, Ag, etc. This is one reason purposely made into a bilayer ground.

176] Moreover, although buffer layers Ta and Ru were divided and considered here, if Ru layer also demonstrates the effect as a buffer layer, there may not be a Ta layer. For example, it is also possible to lose Ta when using Zr layer or a change of Ru.

177] When using a buffer layer, Ti, Zr, W, Cu, Hf, Mo, or these alloys can be used other than Ta. Even if it uses which such material, 2nm - about 5nm of thickness is desirable still more preferably 1nm - 7nm.

178] Although IrMn (Ir:5 - 40at%) was used as an AF film here, as thickness of IrMn, 3nm - about 13nm is desirable. Since the noble metals which fit the narrow gap head towards densification since a pin property also with thin thickness good as a merit using IrMn is realizable are included, the feature that high MR rate of change is maintainable is after heat treatment. By the film used for the antiferromagnetism film, FeMn as shown in the example 2 of comparison is unmaintainable, after heat-treating high MR rate of change. This is a phenomenon which appears notably, when using an ultra-thin free layer like this invention.

179] Moreover, although CrMn, NiMn, and NiO may be used as an antiferromagnetism film, for high MR rate-of-change realization, AF containing a noble-metals element is desirable. For example, you may use Pd, Rh, etc. instead of Ir. Since MR rate of change improves compared with FeMn, NiMn, etc., high MR rate of change is maintained also after annealing heat treatment indispensable to a head. Moreover, it is also one of the desirable examples to use PtMn with the still higher concentration of a noble-metals element.

180]

a5/Cux/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (7-3)

a5/Rux/Cuy/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5(7-4)

is a merit using PtMn (Pt:40 - 65at%), since noble-metals concentration is still higher than IrMn, there can be still less MR degradation by process annealing, high MR rate of change can be realized,  $\Delta R_s$  can be enlarged, and it is mentioned that high power is obtained. In the spin bulb film of the ultra-thin free layer which the good thermal assistance of MR cannot realize easily, MR thermal resistance has the best combination of composition with the ground Cu by the spin-filter effect etc., and PtMn. You may use PdMn and PdPtMn instead of PtMn (noble-metals concentration : 40 - 65at%).

181] When it says from a viewpoint of MR thermal resistance, a certain thing of ground Cu \*\* is desirable 1nm or more. It is because the thermal resistance of MR will become bad if it is the thickness not more than it. However, at a certain time, the thickness of NiFe can secure 4nm or more of thermal resistance of MR, if there is 0.5nm or more of ground Cu \*\*.

182] Since PtMn is large at the value as IrMn also with the almost same value of electric specific resistance, the contribution to a current magnetic field is small desirable. Thus, the film of (7-3) and (7-4) is a film which was very

cellent practically.

[183] However, since it is thicker than the case where the critical thickness out of which the 1 direction anisotropy field comes as a demerit of PtMn is IrMn, it is mentioned that it is difficult to make it thin to about 5nm. Therefore, when PtMn is used, as thickness of PtMn, 5nm - 30nm is desirable. 7nm - about 12nm is desirable still more desirably. Also in PtMn, the view over bilayer-izing of the ground of a free layer as shown in (7-4) is completely the same.

[184] (7-1) As a variation of the example of - (7-4), it is possible to carry out the laminating of the noble-metals element film further on an antiferromagnetism film. For example, you may use a monolayer or cascade screens, such as Au, Ru, Pt, Au, Ag, Re, Rh, and Pd. Low  $H_{in}$  is realizable also in the time of thin spacer thickness with this composition. However, if thickness becomes thick not much, since a current diverging ratio will increase in the upper side of a free layer, as total thickness of a monolayer or a cascade screen, 0.5nm - about 3nm is desirable.

[185] As mentioned above about drawing 15, compared with the examples 1-4 of comparison, the spin bulb film of this example is far excellent in the controllability of the bias point, and can obtain the optimal bias point certainly.

[186] Moreover, as mentioned above about drawing 16, the spin bulb film of this example can obtain high MR rate of change compared with the examples 1-4 of comparison.

Example 2) Top SFSV (simple CoFe free layer)

5/Cux/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (8-1)

5/Cux/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (8-2)

In this example, the simple free lamination which consists of a CoFe monolayer instead of a laminating free layer like NiFe/Co like (an example 1) or NiFe/CoFe as a free layer was used. That is, in drawing 1, it is the structure where the free layer 102 consists of CoFe of a monolayer, and the high conductive layer 101 consists of a monolayer Cu.

[187] Although various difficult points arise in order to realize an ultra-thin free layer which realizes (5nmT in NiFe), the CoFe system free layer which consists of a monolayer, there is a merit of being comparatively easy, from soft-magnetism control in an ultra-thin region being [ film composition ] a monolayer. You may add a thing like B, Cu, Manganese, Rh, Pd, Ag, Ir, Au, Pt, Ru, Re, and Os as the 3rd alloying element to CoFe. However, by pure Co, a soft magnetism is unrealizable instead of a CoFe alloy. Co85Fe15at% - Co96Fe4at% of CoFe is desirable. This is depended on a viewpoint of magnetostriction control so that it may state later.

[188] Moreover, as for a CoFe free layer, it is desirable to carry out fcc (111) orientation from a viewpoint of a soft magnetism. Although fcc (111) orientation is carried out and things are desirable so that resistance may become small so from the point of acquiring the spin-filter effect effectively, the example of the free layer of microcrystal structure like CoFeB or amorphous structure is also considered.

[189] Since  $M_s$  can be realized by thickness thin also for realizing the same  $M_s \cdot t$  from it being larger than NiFe, a simple CoFe free layer becomes advantageous also from a viewpoint of the spin-filter effect. For example, to total thickness becoming about 4nm by NiFe/CoFe NiFe3.6/CoFe0.5 (nm), for realizing the free layer of 4.5nmT(s), in a simple CoFe free layer, it is CoFe2.5nm and about 1.5nm is thinly made rather than NiFe/CoFe. If a high conductive layer is prepared in these both film in contact with the bottom of a free layer, although filter out of both film is carried out since it is thick compared with about 1nm which is the value of the mean free path of down spin, a down spin electron. Since it will become the mean free path of rise spin, and a near value if it becomes about 4nm of total thickness of NiFe/CoFe, the high conductive layer under it will bring about a simple shunt effect, and the more it thickens a high conductive layer, the more MR will reduce it under the influence of a shunt effect.

[190] On the other hand, about simple CoFe, since the mean free path is longer than 2.5nm, the mean free path of rise spin becomes long, so that a certain amount of thickness attaches a high conductive layer, and MR goes up. When Cu is experimentally used for a high conductive layer and the total thickness of the free layer which consists of Cu layer, NiFe/CoFe, or a CoFe layer is about 4nm or 3nm - 5nm, taking MR peak is acquired experimentally. That is, by CoFe, although reduction in MR is brought about rather than the spin-filter effect in NiFe/CoFe for a shunt effect when there is required high conductive-layer thickness on a bias point design, since coexistence of the MR elevation effect can be aimed at with bias point adjustment, it becomes advantageous according to the spin-filter effect. The thickness of Cu layer which takes MR peak becomes a bird clapper thickly, and the combination effect of the spin-filter effect and the bias point adjustment effect comes out of this, so that CoFe thickness is thin as mentioned above, since MR peak value is decided by total thickness of a high conductive layer and a free layer. The simple CoFe free layer is more desirable by the spin-filter spin bulb by the above reason.

[191] Since laminating NiFe/CoFe of MR thermal resistance is worse, since the simple CoFe free layer is larger, MR's is good.

[192] The monolayer of CoFe is easier for control than NiFe/CoFe whose magnetostriction control is also the cascade screen of an ultra-thin layer. Especially, NiFe/CoFe whose one interface increases in an ultra-thin free layer since the interface magnetostriction is important is more disadvantageous.

0193] The bias point in the composition of (8-1) as well as [ almost ] the case of an example 1 becomes within 30 - 0% of good limits. It is small like [ a height dependency ] an example 1.

0194] Since the saturation magnetic field  $H_s$  on a transfer curve becomes small about the  $M_s \cdot t$  dependency of a free layer so that  $M_s \cdot t$  is small, stricter bias point adjustment is required. Since it becomes important to specifically reduce current magnetic field more, the need of making the thickness of a high conductive layer increasing comes out. By the spin bulb film by this invention, in order that the thickness of a high conductive layer in which MR peak appears according to the spin-filter effect may shift to the thicker one so that the thickness of a free layer becomes thin, as already stated, it turns out that the trend is in agreement and the design concept of the spin bulb film of this invention suits \*\* as a film of the head for high-density.

0195] At the time of free layer  $M_s \cdot t$ -4.5nmT and 2.5nm of CoFe thickness, the good thickness of a high conductive layer by Cu conversion specifically 0.5nm - 4nm, At the time of 1nm - 3nm,  $M_s \cdot t$ -3.6nmT, and 2nm of CoFe thickness, they are Cu film conversion still more desirably. 1nm - 4.5nm is Cu film conversion still more desirably at the time of 1.5-3.5nm,  $M_s \cdot t$ -2.7nmT, and 1.5nm of CoFe thickness. Still more desirably, at the time of 2nm - 4.5nm,  $M_s \cdot t$ -1.8nmT, and 1nm of CoFe thickness, it is Cu film conversion and 1.5nm - 2nm - 5.5nm 5nm is set to 2.5nm - about 5nm still more desirably.

0196] By (8-2), PtMn is used to using IrMn as an antiferromagnetism film in (8-1). By using PtMn, MR thermal assistance improves further and the merit that improvement in an output can be aimed at is obtained. This is the same as that of the time of a NiFe/Co(Fe) free layer. However, since there is a trouble that  $H_{in}$  tends to go up [ the way when using PtMn ], in order to design the bias point at a good place, the cure of whether the current magnetic field  $H_{cu}$  is reduced, or either or both  $H_{pin}$  increase is more nearly required than the time of using IrMn. [ both ] In order to reduce  $H_{cu}$ , sigma of a high conductive layer is made to increase, that is, it can consider making the thickness of a high conductive layer increase. Moreover, in order to make  $H_{pin}$  increase, it is possible to make the pin layer membrane thickness difference of the upper and lower sides of synthetic AF slightly larger than the time of IrMn. However, since it also becomes causing the fall of  $\Delta R_s$ , adjustment in the range of about 0-2nm is more desirable [ making the thickness of a high conductive layer increase ] than the time of IrMn at Cu conversion in high conductive-layer thickness. Moreover, since it becomes also making MR height dependency of the bias point increase as stated so far, as for making  $\Delta R_s$  of synthetic AF structure increase, it is desirable to design by the increase in about 0-1nm by CoFe conversion compared with the time of IrMn desirably [ enlarging not much ]. The following composition is also considered as a variation of (8-1) and (8-2). Ta5/RuX/CuY/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 Ta(8-3) /RuX/CuY/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 In this (8-4) composition, it constituted from a cascade screen called Ru/Cu instead of Cu monolayer as a high conductive layer. The reason made into a cascade screen is based on the following two reasons.

0197] 1. About CoFe magnetostriction control of CoFe magnetostriction control 2.  $H_{in}$  reduction effect above-mentioned 1., it is going to control a magnetostriction by strain control of CoFe to explain in full detail behind. That is, when a simple Cu twist also extends the fcc-d (111) spacing of CoFe and a Co90Fe10 (atmic%) free layer is used, it is going to control near the zero the magnetostriction of the CoFe free layer which is easy to become large at a negative side. Therefore, as a material located under Cu layer, what has a larger atomic radius than Cu is desirable. For example, Fe, Au, Ag, aluminum, Pt, Rh, Ir, or Pd is [ other than Ru ] desirable. It is possible also by changing the CoFe composition other than the formation of a ground bilayer from 90-10 in a meaning called magnetostriction control. Specifically, the CoFe alloy free layer of the composition range of Co90Fe10-Co96Fe4 is used. It is because the effect of raising the flat nature at the time of film growth is in Ru about the  $H_{in}$  reduction effect of above-mentioned 2. on the other hand. As already stated,  $H_{in}$  is because it is desirable to carry out a bias point design by  $H_{cu}$  and  $H_{pin}$  in the smallest possible place. especially, in SFSV, the thinner one is desirable as it cuts with the point which is two called  $H_{in}$  reduction of the spin-filter effect of MR, and the upper layer of a free layer gaily [ spacer thick ], and since the technology of mastering the ultra-thin spacer which is about Cu-2nm is required, generally the  $H_{in}$  control with a big spacer thick dependency becomes difficult By making it a Ru/Cu cascade screen, it can be called Ru1.5 nm/Cu1nm - nm ground, free layer  $M_s \cdot t$ 3.6nmT, an ultra-thin free layer called 2nm of CoFe thickness, and spacer Cu2nm, and low  $H_{in}$  called 7-13Oe can be realized as  $H_{in}$ . When it takes into consideration that  $H_{in}$  was about 20 Oes in the example of (7-1) and (7-2), this  $H_{in}$  reduction effect is large.

0198] What is necessary is just to only convert into sigma and Cu thickness from the specific resistance of Ru, when seen from a viewpoint of  $H_{cu}$  calculation. Since the specific resistance of Ru which was able to be found experimentally is 30microomegacm, as a shunt effect of sigma, it will be made Cu thickness of specific resistance 10microomegacm, and will be called one third of thickness. For example, with composition called Ru1.5 nm/Cu1nm, it will be said with Cu thickness reduced property of a shunt that it is equivalent to  $(1.5nm/3)+1nm=1.5nm$ .

0199] Moreover (8-1), as a variation of the example of - (8-4), it is possible to carry out the laminating of the noble-

metals element film further on an antiferromagnetism film. For example, you may use a monolayer or cascade screens, such as Cu, Ru, Pt, Au, Ag, Re, Rh, and Pd. Low  $H_{in}$  is realizable also in the time of thin spacer thickness with this composition. However, if thickness becomes thick not much, since a current diverging ratio will increase in the upper layer side of a free layer, as total thickness of a monolayer or a cascade screen, 0.5nm - about 3nm is desirable.

Example 3) Bottom SFSV (NiFe/Co(Fe) free layer)

'a5/Ru2/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu2/Ta5 (9-1)

'a5/Ru1/NiFeCr2/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu2/Ta5(9-2)

an antiferromagnetism film shows the so-called bottom type located in a lower layer side rather than a free layer of example. Drawing 6 is a conceptual diagram showing the spin bulb film composition concerning this example. That is, in the ground buffer layer 131, the laminating of the antiferromagnetism film crystal control layer 128 and the antiferromagnetism film 127 was carried out, and the pin layers 126 and 124 have joined together in antiferromagnetism through a layer 125. On the layer 124, the laminating of the spacer layer 123, the free layer 122, and the nonmagnetic quantity conductive layer 121 is carried out one by one, and, finally the cap layer 132 is formed. [200] The antiferromagnetism film crystal control layer 128 consists of a monolayer Ru, and the antiferromagnetism film of 127 of the example of (9-1) is the case where PtMn and the free layer 122 are formed from the cascade screen of the bilayer of 129 and 130. The antiferromagnetism film crystal control layer 128 is formed from the bilayer film of NiFeCr as Ru and a film of 134 as a film of 133, and the antiferromagnetism film of 127 of the example of (9-2) is an example when IrMn and a free layer are formed from 129 and the two-layer film of 130.

[201] In a bottom type spin bulb film, 1nm - about 5nm of ground films of fcc or hcp is further used as an antiferromagnetism film crystal control layer on buffer layers, such as Ta. For example, Cu, Au, Ru, Pt, Rh, Ag, nickel, NiFe, those alloy films, a cascade screen, etc. are used. These seed (seed) layers are important films in order to raise the function as an antiferromagnetism film. In the example of PtMn of (9-1), the cascade screen of Ru/NiFeCr was used for Ru layer of a monolayer in the example of IrMn of (9-2). Making blocking temperature of an antiferromagnetism film into a sufficiently high value and film flattening are urged to this antiferromagnetism film crystal control layer, and even when the 1.5nm - about 2.5nm ultra-thin spacer needed by this invention is used, it has the work which realizes low  $H_{in}$ .

[202] In respect of the bias point merit by this invention, it is not influenced [ big ] according to the kind of this seed layer in the range of the thickness about [ above-mentioned ] an example. However, it is not desirable to use low electrical resistance materials, i.e., a small material of specific resistance. This is because it will become difficult to bring a current center close to a free layer if a shunt diverging layer increases here. Therefore, it is desirable to use the material of high resistance as much as possible in the range of the material which has a function as an antiferromagnetism film raised. For example, instead of NiFe of low resistance, Cr, Nb, Hf, W, Ta, etc. are added to NiFe, and the example which raises and uses specific resistance can be considered. In (9-2), NiFeCr is used instead of NiFe.

[203] As an antiferromagnetism film, PtMn is used in (9-1) and IrMn is used by (9-2). As a merit using PtMn, that blocking temperature is an elevated temperature,  $H_{u.a.}$ 's being large, and MR heat deterioration after process heat treatment are very small, and it is mentioned that high MR and quantity  $\Delta R_s$  are realizable. When an ultra-thin free layer is used like the time of a top type, the merit using PtMn which is the antiferromagnetism film which contains noble metals from the point that high MR is maintainable after process heat treatment is very large. You may use dPtMn instead of PtMn. As a desirable thickness range, 5nm - 30nm 7nm - 12nm is good still more preferably.

[204] As a merit using IrMn of (9-2), since a property comes out in a thin film field rather than PtMn, the point of being suitable for the narrow gap head corresponding to densification can be mentioned. As thickness of IrMn, 3nm - 3nm is desirable. Since it is the antiferromagnetism film with which IrMn also contains the noble-metals element Ir, it excels in the thermal resistance of MR rate of change. You may use RuRhMn which contains a noble-metals element similarly instead of IrMn.

[205] As mentioned above, as an antiferromagnetism film, although PtMn, IrMn, and PdPtMn are the most desirable, in respect of the bias point merit of the spin bulb film of this invention, it is not limited by antiferromagnetism film material and the antiferromagnetism film of others of NiO, CrMnPt, NiMn, and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> grade may be used.

[206] As a ferromagnetic material of the bilayer of a synthetic pin layer, although the CoFe alloy layer was used here, you may use the cascade screen of Co, NiFe or NiFe, and Co or CoFe. Views, such as such components, thickness, etc., are completely the same as that of the top type case of the examples 1 and 2 mentioned above. The composition of this synthetic pin layer that is the important point of this invention is the purpose with biggest reducing a pin disclosure magnetic field as mentioned above, and the  $M_s \cdot t$  difference of this vertical ferromagnetism layer is closely connected with the thickness of a high conductive layer prepared in contact with a free layer, and is changed.

[207] The time of a top type and a view do not change about a spacer, either, but the thinner possible one is desirable.

Specifically, 1.5nm - about 2.5nm is desirable still more desirable, and 1.8nm - 2.3nm is desirable.

[208] As a free layer, the cascade screen of NiFe/Co is used in the example here. The thickness of this free layer and the view of material are the same as that of the time of a top type almost. However, in the case where the ground films of NiFe are a top type and a bottom type, since it differs, when composition of NiFe for low magnetostriction realization is a top type, it differs a little. Specifically, in the case of a NiFe/CoFe laminating free layer, since it is smaller than the time of the shift by the side of positive [ of the magnetostriction of the NiFe/CoFe laminating free layer accompanying the reduction in the thickness of NiFe ] being a top type, the thing of nickel PUA can also realize the optimal magnetostriction as composition of NiFe rather than the time of a top type.

[209] For example, in the case of a NiFe3 nm/CoFe0.5nm laminating free layer, by the top type, it becomes a still large value to a positive side by nickel81Fe19 (at%) as composition of NiFe, and although it is unusable, by the bottom type, it becomes a positive small magnetostriction value by nickel81Fe19 (at%), and becomes the film which is satisfactory practically.

[210] Cu film is used here as a high conductive layer which is the 2nd of the big points of this invention. This biggest role of a high conductive layer is bringing a current pin center, large close to a free layer as much as possible, and reducing a current magnetic field.

[211] in spite of using the well which also uses the spin-filter effect of MR by Cu conductive layer as still more nearly another effect, and the ultra-thin free layer, there is no degradation of MR rate of change

[212] The range of optimal Cu thickness is the same as that of the time of Top SFSV, and it is the same as that of the time of a top type that an optimum value shifts delicately according to the pin layer membrane thick difference of the upper and lower sides of free thickness and synthetic AF. Moreover, it is in low  $H_{in}$  in an ultra-thin free layer being realizable as another big effects other than bias point adjustment of Cu cap layer, and high MR rate-of-change maintenance. For example, when there is no Cu cap at the same free thickness, and a thing with 30 or more Oe(s) of  $H_{in}$ (s) uses Cu cap, it can decrease up to about 10 Oe(s).

[213] the high conductive layer of the high conductive layer Cu which touched the free layer CoFe as a variation of (9-1) and (9-2) here which becomes replacing from the cascade screen more than a bilayer -- composition -- the bottom is also good For example, Cu/Ru, Cu/Re, Cu/Rh, Cu/Pt, etc. are mentioned. since the magnetostriction of a CoFe free layer is influenced by distortion as an effect made into a bilayer as described at the time of a top type, it is the main purposes to adjust magnetostriction  $\lambda$ das Moreover, although it is important in this invention to realize low  $H_{in}$ , it may be made two-layer also for the low  $H_{in}$  control purpose.

[214] The following can be considered as concrete film composition.

[215]

a5/Ru/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu1.5/Ru1.5/Ta5 (9-3)

a5/Ru/NiFeCr/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu1.5/Ru1.5/Ta5(9-4)

1 the above-mentioned film composition, to specific resistance 10microomegacm of Cu thin film, since Ru is 0microomegacm, as an electric shunt effect, Ru3nm will bring about an equivalent effect to Cu1nm. That is, in the above (9-3) and the film of (9-4), the thickness of a high conductive layer will say that it is equivalent to 2nm by Cu conversion. Since it is used in the range to 0.5nm - 3nm in the case of Cu monolayer, Ru is similarly used in 0.5nm - nm. However, as a high conductive layer which touches CoFe, since it is not desirable from the point of a narrow gap to make Ru not much thick, after using 0.5nm - about 2nm of Cu thickness using Cu etc. by carrying out in contact with CoFe, it is desirable [ the Cu is more desirable, and ], since [ that specific resistance is also high in Ru ] the spin-filter effect is weaker than the case of Cu to use other two-layer metallic materials.

Example 4) Bottom SFSV (CoFe free layer)

a5/Ru2/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu2/Ta5 (10-1)

a5/Ru1/NiFeCr2/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu2/Ta5 (10-2) this example It is the thing of the type with which it belongs to the bottom type illustrated to drawing 2 , and the CoFe layer of a monolayer is used instead of the free layer 122. Except it, it is the same as that of the example 3 mentioned above. The material of layers other than the free layer and the view of thickness are completely the same as that of an example 3. The merit using a CoFe free layer is the same as that of the time of a top type. In this example,  $M_s \cdot t$  by NiFe conversion at the time of 3.6nmT(s) furthermore, but As opposed to the spin-filter effect being thinly acquired by 2.5nm of thickness, if it is a CoFe monolayer free layer when  $M_s \cdot t$ -4.5nmT compares If it is NiFe/Co (Fe), NiFe4/Co0.5 (nm) and the total thickness will become thick, and the spin-filter effect of MR by preparing a high conductive layer is not acquired. A simple shunt layer and a bird clapper, And the shunt effect of the NiFe itself also decreases 0 to 30% by  $\Delta R_s$  from a certain thing compared with a CoFe monolayer free layer.

[216] this example which is an example of a CoFe free layer also from the spin-filter effect of  $M_s \cdot t$  being acquired from the above thing in the latus range of  $M_s \cdot t$  is more desirable than the case of an example 3.

217] the high conductive layer of the high conductive layer Cu which touched the free layer CoFe as a variation of 0-1) and (10-2) here which becomes replacing from the cascade screen more than a bilayer -- composition -- the bottom is also good For example, Cu/Ru, Cu/Re, Cu/Rh, etc. are mentioned. since the magnetostriction of a CoFe free layer is influenced by distortion like previous statement as an effect made into a bilayer, it is the main purposes to just magnetostriction lambdas Moreover, although it is important in this invention to realize low  $H_{in}$ , it may be made two-layer also for the low  $H_{in}$  control purpose. The following can be considered as concrete film composition.

15/NiFe/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu1.5/Ru1.5/Ta5(10-3)

15/NiFe/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu1.5/Ru1.5/Ta5 (10-4)

There is also magnetostriction control by changing composition of CoFe in addition to the method of controlling the magnetostriction of CoFe by the above cascade-screen nonmagnetic quantity conductive layers. Although the way of a round film generally tends to do the distorted adjustment which joins a free layer, it is because it becomes difficult to choose the material in the free layer bottom freely by the bottom type. If the laminating of the CoFe will be carried out with Cu at the time of a bottom type and Co90Fe10 (at%) is then used, it will be easy to become the big magnetostriction on a negative side. in order to shift it to a positive side -- Co -- it is desirable to use rich CoFe Specifically, it is Co90Fe10-. It is desirable to use the CoFe free layer of Co96Fe4 (at%). however, Co -- if it is made rich and a hcp phase is intermingled, since the soft magnetism of a free layer will deteriorate ( $H_c$  increases), it is not desirable to use a CoFe alloy like Co98Fe2 over which it passes richly [ Co ]

218] In the above-mentioned film composition, to specific resistance 10microomegacm of Cu thin film, since Ru is 1microomegacm, as an electric shunt effect, Ru3nm will bring about an equivalent effect to Cu1nm. That is, in the above (10-3) and the film of (10-4), the thickness of a high conductive layer will say that it is equivalent to 2nm by Cu conversion. Since it is used in the range to 0.5nm - 3nm in the case of Cu monolayer, Ru is similarly used in 0.5nm - 1nm. However, as a high conductive layer which touches CoFe, since it is not desirable from the point of a narrow gap to make Ru not much thick, after using 0.5nm - about 1nm of Cu thickness using Cu etc. by carrying out in contact with CoFe, it is desirable [ the Cu is more desirable, and ], since [ that specific resistance is also high in Ru ] the spin-torque effect is weaker than the case of Cu to use other two-layer metallic materials.

The 2- gestalt : improvement in high temperature oxidation stability and a reproduction output of the 6th operation) Next, the gestalt of the 2nd - the 6th operation of this invention seen from a viewpoint of improvement in high temperature oxidation stability and a reproduction output is explained.

219] First, it outlines about technical thought common to the gestalt of the 2nd - the 6th operation.

220] Drawing 17 is drawing showing the gestalt of the 1 operation of the gestalten of the 2nd - the 6th operation of this invention. In drawing 17, the lower shield 11 and the lower gap film 12 are formed in a substrate 10, and the spin bulb element 13 is formed on it. A spin bulb element consists of a spin bulb film 14, a vertical bias film 15 of a couple, and an electrode 16 of a couple, and the nonmagnetic ground layers 141 and 142, the antiferromagnetism layer 143, the magnetization fixing layer 144, the interlayer 145, the magnetization free layer 146, and the protective coat 147 are formed further.

221] Resistance rate-of-change  $\Delta R/R$  of the material composition and thickness of an antiferromagnetism layer which are combined with the ferromagnetic layer of SyAF at the time of using SyAF of the gestalt of operation of this invention for a magnetization fixing layer, the switched connection constant J in 200 degrees C and exchange bias magnetic field  $H_{UA}^*$  and  $H_{UA}$ , the blocking temperature  $T_b$ , and a spin bulb element is shown in Table 6. Moreover, the same table at the time of using the magnetization fixing layer of the conventional monolayer as a magnetization fixing layer is shown in Table 7. Moreover, the relation between the switched connection constant J of rocking curve half-value-width  $\Delta\theta$  of the diffraction line peak from the maximum \*\*\*\* of the antiferromagnetism layer combined with SyAF and the antiferromagnetism layer side ferromagnetism layer of SyAF in 200 degrees C and the blocking temperature  $T_b$  is shown in Table 8.

222]

Table 1]

E8

スピバルブ膜構成:

基板/Ta (5nm)/NiFe/CoFe/Cu (3nm)/CoFe (2.5nm)  
 /Ru (0.9nm)/CoFe (2.5nm)/反強磁性層/Ta (5nm)

反強磁性層 材料	膜厚 (nm)	200℃における J (erg/cm <sup>2</sup> )	200℃における H <sub>ex</sub> (Oe)	ブロッキング 温度T <sub>b</sub> (℃)	抵抗変化率 ΔR/R (%)
Ir <sub>22</sub> Mn <sub>78</sub>	5	0.04	400	250	7.3
	7	0.045	450	270	7.3
	10	0.045	450	290	7
	20	0.04	400	300	6.5
	30 (比較例)	0.035	350	300	5.5
Rh <sub>20</sub> Mn <sub>80</sub>	7	0.025	250	235	7.1
	10	0.035	350	260	6.8
Rh <sub>14</sub> Ru <sub>7</sub> Mn <sub>79</sub>	7	0.02	200	225	7.2
	10	0.03	300	245	6.8
Pt <sub>53</sub> Mn <sub>47</sub>	10	0.02	250	290	7.9
	15	0.025	400	320	7.4
	20	0.1	>600	350	7
	30 (比較例)	0.12	>600	370	6.2
Ir <sub>50</sub> Mn <sub>50</sub>	15	0.02	250	300	6.8
IrMnPt	15	0.02	200	240	6.9

IrMn, RhMn, RhRuMn, CrMnPtを用いたスピバルブ膜:

270℃、1時間の熱処理を施した後の結果

PtMn, NiMnを用いたスピバルブ膜:

270℃、10時間の熱処理を施した後の結果

223]

Table 2]

7

スピバルブ膜構成:

基板/Ta (5nm)/NiFe/CoFe/Cu (3nm)/CoFe (2.5nm)  
 /反強磁性層/Ta (5nm)

反強磁性層 材料	膜厚 (nm)	200℃における J (erg/cm <sup>2</sup> )	200℃における H <sub>ex</sub> (Oe)	ブロッキング 温度T <sub>b</sub> (℃)	抵抗変化率 ΔR/R (%)
Ir <sub>22</sub> Mn <sub>78</sub>	5	0.04	170	250	6.6
	10	0.045	190	290	6.2
Pt <sub>51</sub> Mn <sub>49</sub>	10	0.03	130	300	7.2
	20	0.1	430	350	6.7
	30	0.12	510	370	6.4

IrMnを用いたスピバルブ膜: 270℃、1時間の熱処理を施した後の結果

PtMnを用いたスピバルブ膜: 270℃、10時間の熱処理を施した後の結果

224]

Table 3]

反強磁性層 材料	膜厚 (nm)	最密面ピークのロッキング カーブ半値幅 $\Delta \theta$ (°)	200℃における J (erg/cm <sup>2</sup> )	ロッキング 温度 T <sub>b</sub> (°C)
r 22Mn78	5	12	0.01	210
	5	8	0.025	230
	5	5	0.045	250
	5	3	0.05	250
t h 20Mn80	7	13.5	~0	190
	7	8	0.02	225
	7	4	0.025	235

is invention person constitutes the magnetization fixing layer combined with 1 antiferromagnetism layer by SyAF, as shown in Table 6 and 8. They are 0.02 erg/cm<sup>2</sup> as a switched connection constant J in the temperature of 200 degrees C if composition of an antiferromagnetism layer is chosen. The above can be obtained, 2) when carrying out orientation of the maximum \*\*\*\* so that the rocking curve half-value width of the maximum \*\*\*\* peak of an antiferromagnetism layer may become small, and making it 8 degrees or less of rocking curve half-value width become degrees or less still more preferably preferably That the switched connection constant J in the temperature of 200 degrees C can be raised, and by setting more preferably 20nm or less of magnetic thickness of 3 antiferromagnetism layers to 10nm or less It is the switched connection constant J in that it can raise more than equivalent with the resistance rate of change of the spin bulb element which constituted resistance rate of change using the magnetization fixing layer of a monolayer, and 4 temperature of 200 degrees C 0.02 erg/cm<sup>2</sup> By carrying out above It sets in temperature of 200 degrees C, and is exchange bias magnetic field HUA\*. It could be made 200 or more Oes, and even the maximum magnetic fields which join the spin bulb element of a reproduction element from a record medium etc. are 200Oe(s), it finds out that a stable magnetization fixing layer is obtained, and came to make this invention.

1225] Drawing 18 is [ the change of the resistance of a spin bulb film to an external magnetic field, and ] exchange bias magnetic field HUA\*. It is the shown \*\* type view. It is exchange bias magnetic field HAU\* at drawing 18 . It is defined as the value of the magnetic field which calculated the maximum of the magnetic field by which magnetization of a magnetization fixing layer does not move substantially as an intersection of the extension wire of the bay by the side of a low magnetic field, and the extension wire of the bay of a high magnetic field. exchange bias magnetic field HUA\* \*\*\*\*\* -- in resistance-magnetic influence when the magnetization fixing layer which has 200 or more Oes adds an external magnetic field in the magnetization fixing direction, resistance change magnetization hardly moved in the magnetic field range to 200Oe, and only the magnetization free layer carried out [ change ] the magnetization response is obtained

1226] After the magnetic field which is the operating point as a magnetic field sensor is accepted near the zero on the curve only the steep resistance change accompanying the magnetization response of a magnetization free layer indicates resistance-magnetic influence to be, and change of resistance is not accepted to the external magnetic field to 200Oe other than the magnetization response of this magnetization free layer but a magnetization free layer is saturated with drawing 18 , it is shown that there is no substantial response to a magnetic field.

1227] When a conventional NiO antiferromagnetism layer and a conventional FeMnCr antiferromagnetism layer are used, in 200 degrees C, J is hardly obtained. Moreover, since resistance rate of change becomes lower than the magnetization fixing layer of the conventional monolayer when the CrMnPt antiferromagnetism layer of 30nm \*\* is used, it is not desirable.

1228] In the magnetization fixing layer of the conventional monolayer, although high HUA is obtained by 20nm thick or less when PtMn is used as shown in Table 7, the resistance rate of change in that case indicates a low value comparatively to be 6.4 - 6.7%.

1229] On the other hand, it is HUA\* at 200 degrees C by using an antiferromagnetism layer with a thickness [ , such as Mn, RhMn, RhRuMn, PtMn, NiMn, and CrMnPt, ] of 20nm or less according to the gestalt of operation of this invention shown in Table 6. The outstanding thermal resistance of 200 or more Oes is satisfied, and, moreover, resistance rate of change's being equivalent to the case the magnetization fixing layer of the conventional monolayer being used, or the value beyond it is acquired. In addition, in this invention, the minimum of antiferromagnetism layer thickness is 3nm or more preferably.

1230] Drawing 19 is HUA\*. The relation between elapsed time when the spin bulb film of the operation gestalt of this invention of 200Oe(s) and the conventional HUA give the simulation bias magnetic field of 200Oe(s) at 200 degrees C

out the spin bulb film of the monolayer magnetization fixing layer of 500Oe(s), and the angle by which magnetization of a magnetization fixing layer moved is shown. The spin bulb film of the operation gestalt of this invention is HUA\* in 200 degrees C [ as shown in drawing 19 / the spin bulb film of the conventional monolayer magnetization fixing layer ]. In spite of being small compared with 200Oe(s), and HUA of a monolayer magnetization fixing layer and 510Oe, it turns out that aging of the fixing magnetization in 200 degrees C is slight, and it excels in ability.

[231] moreover, Mn, such as IrMn, RhMn, and RhRuMn, -- in antiferromagnetism thickness 10nm or less, large resistance rate of change is obtained and it is still more desirable than the case where the magnetization fixing layer of the conventional monolayer is used so that it may see, when a rich gamma-Mn system antiferromagnetic substance film is used

[232] Moreover, in the form of operation of this invention of Table 6, the antiferromagnetism layer of the range whose Tb is 240-300 degrees C shows the thermal resistance of good fixing magnetization. Therefore, since the magnetization direction of a magnetization fixing layer is freely controllable by the external magnetic field by adding the big magnetic field exceeding the joint magnetic field of a magnetic coupling layer near the Tb, and saturating the ferromagnetic layer A and the ferromagnetic layer B in this direction, the magnetization fixing processing of diffusion between a magnetic coupling layer, and the ferromagnetic layer A and the ferromagnetic layer B at 300 degrees C or less which seldom poses a problem is attained.

[233] In order to prevent the influence of diffusion between a magnetic coupling layer, and the ferromagnetic layer A and the ferromagnetic layer B, or diffusion, it is desirable that thickness exceeds 0.8nm as a magnetic coupling layer, and it is desirable to use Ru, Rh, Cr, Ir, etc. Moreover, it is effective in the ferromagnetic layer A and the ferromagnetic layer B to use Co alloys, such as CoFe, and equivalent [ to the thickness of a magnetic coupling layer ] or to hold down the irregularity of a magnetic coupling layer to less than [ it ].

[234] furthermore, in the magnetization direction convention heat treatment of a magnetization fixing layer Since it is necessary to saturate the ferromagnetic layer A and the ferromagnetic layer B in this direction, if the thickness of the ferromagnetic layer A and the ferromagnetic layer B becomes thin to about 2nm When magnetic coupling thickness is 0.8nm or less, the antiferromagnetism-joint magnetic field of a magnetic coupling layer will increase more than about 7 Oe(s) or it, and the magnetization direction convention heat treatment of a magnetization fixing layer will become difficult by the practical external magnetic field. For this reason, the magnetization direction convention heat treatment of a magnetization fixing layer is possible for magnetic coupling thickness, and it is desirable at an external magnetic field with more practical making it the thickness exceeding 0.8nm, for example, 7kOe(s).

[235] In the SyAF magnetic coupling layer adopted in the form of operation of this invention of Table 6, by considering as the thickness of 0.9nm of the magnetic coupling layer by which the thickness of the ferromagnetic layer which consisted of CoFe alloys, and the ferromagnetic layer B was constituted from 2.5nm and Ru, antiferromagnetism joint magnetic fields are about 4 kOe(s), and can perform heat-resistant reservation of a magnetization fixing layer good enough by the antiferromagnetism magnetic field of this level.

[236] In this invention, the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, or composition with the magnetic thickness of the ferromagnetic layer A thicker than the magnetic thickness of the ferromagnetic layer B is desirable. When the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, compared with the case where the magnetic thickness of the ferromagnetic layer A is thicker than the magnetic thickness of the ferromagnetic layer B, magnetization of a magnetization fixing layer is remarkably stable to a medium magnetic field or a vertical bias magnetic field.

[237] On the other hand, when the magnetic thickness of the ferromagnetic layer A is larger than the magnetic thickness of the ferromagnetic layer B, compared with the case where the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, a good ESD property without the fixing flux reversal by ESD can be realized. In this case, it is desirable that the ratio of the magnetic thickness of the ferromagnetic layer B to the magnetic thickness of the ferromagnetic layer A considers as the range of 0.7-0.9. For example, it is desirable to consider [ the ferromagnetic layer A ] as a 2nm CoFe alloy at a 2.5nm CoFe alloy and the ferromagnetic layer B. Even when the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, even if the fixing flux reversal by ESD arises by what the circuit which re-fixes magnetization of a magnetization fixing layer in the predetermined direction by current is included in a magnetic disk drive for (for example, U.S. Pat. No. 5650887), the drive which can re-fix can be realized. The values of J in 200 degrees C are 0.02 erg/cm<sup>2</sup>. In order to realize the above The gamma-Mn phase which consists of IrMn, RhMn, RhRuMn, etc. which make Mn a principal component, Or the antiferromagnetism layer (it is easy to realize composition of Mn at less than 40% exceeding 0) which makes the rule-ized phase of an AuCuII form the main phase Or it is desirable to use the antiferromagnetism layer (for it to be easy to realize Mn composition at 70% or less 40% or more) containing the rule-ized phase (CuAuI type) of the face-

entered tetragon which consists of PtMn, PtPdMn, NiMn, etc., or Cr system antiferromagnetism layers, such as CrMn and CrAl.

0238] The values of  $J$  [ in / 200 degrees C / furthermore / with these alloys ] are 0.02 erg/cm<sup>2</sup>. In order to realize the above in the thin antiferromagnetism layer from which high resistance rate of change is obtained, it is required to realize the crystal structure in which the maximum \*\*\*\* carried out orientation.

0239] For rocking curve half-value-width  $\Delta\theta$  of the diffraction line peak from the maximum \*\*\*\* and half-value-width [ from the relation between  $T_b$  and  $J$  ]  $\Delta\theta$  showing the amount of preferred orientation shown in table 8 which are a parameter, the values of  $J$  are 0.02 erg/cm<sup>2</sup> at 8 degrees or less. It turns out that the above is obtained and the magnetoresistance-effect head of this invention can be realized. If the maximum \*\*\*\* carries out orientation to face-centered tetragons, such as PtMn, similarly in the rule-sized antiferromagnetism layer of bcc systems, such as an antiferromagnetism layer and CrMn,  $J$  high  $T_b$  in thin antiferromagnetism thickness and high at 200 degrees C is realizable. here -- the maximum \*\*\*\* -- in the case of a fcc phase, in the case of a hcp phase, a peak (102) is meant, and, as for the case of a bcc phase, a peak (110) is meant for a peak (111), respectively Moreover, in PtMn containing the rule-sized phase which consists of a face-centered tetragon etc., it means that the fcc phase which remains is carrying out plane orientation (111), or that the rule-sized field (111) of a face-centered tetragon is carrying out orientation. In addition, in the case of a fcc phase or a hcp phase, a stacking fault may also be included.

0240] In addition, as shown in drawing 20, the fluctuation from the film surface perpendicular direction of the maximum \*\*\*\* spot in the transmission-electron-microscope diffraction image from a head cross section can also express the rocking curve half-value width of the diffraction line peak from the maximum \*\*\*\*, and the rocking curve half-value width and the fluctuation angle of the maximum \*\*\*\* spot of a transmission-electron-microscope diffraction image by X-ray diffraction are in agreement in general.

0241] In order to realize such a good maximum \*\*\*\* array, membrane formation of a spin bulb film is performed in the atmosphere which suppressed impurities, such as oxygen gas, as much as possible. For example, the membrane formation by the equipment by which preliminary exhaust air is made even on a 10<sup>-9</sup>Torr base, 500 ppm Membrane formation using the spatter target which suppressed the oxygen content below, The membrane formation given in case spatter atom deposits moderate energy on a substrate by methods, such as a substrate bias spatter There are methods, such as preparing nickel system alloy layers, such as a noble-metals simple substance or alloy ground layers, such as a ground layer, for example, Au, Cu, Ag, Ru, Rh, Ir, Pt, Pd, etc., and NiFe, NiCu, NiFeCr, NiFeTa, between an alumina gap layer and a spin bulb film.

0242] As mentioned above, it outlined about the technical thought [-like in common ] about the gestalt of the 2nd of this invention about "improvement in thermal resistance and a reproduction output" - the 6th operation.

0243] Next, the gestalt of the 2nd - the 6th operation of this invention is explained in detail.

0244] (Gestalt 2 of operation) An example of the magnetoresistance-effect head which starts this operation gestalt at drawing 17 is shown. In drawing 17, the lower shield 11 and the lower gap film 12 are formed in the Al (nickel, chromium, TiO<sub>3</sub> and TiC) substrate 10, and the spin bulb element 13 is formed on it. The lower shields 11 are NiFe which has the thickness of 0.5-3 micrometers, Co system amorphous magnetism alloy, a FeAlSi alloy, etc., and it is desirable to remove surface irregularity by polish with NiFe or a FeAlSi alloy here. Moreover, an alumina with a thickness of 5-100nm, nitriding aluminum, etc. are used for the lower gap film 12.

0245] A spin bulb element consists of a spin bulb film 14, a vertical bias film 15 of a couple, and an electrode 16 of a couple. A spin bulb film consists of protective coats 147 with a thickness of 0.5-10nm the 2nd ground layer 142 with a thickness of 0.5-5nm, the antiferromagnetism layer 143, the magnetization fixing layer 144, the interlayer 145 with a thickness of 0.5-4nm, the magnetization free layer 146, and if needed the nonmagnetic ground layer 141 with a thickness [ , such as Ta, Nb, Zr, and Hf, ] of 1-10nm and if needed.

0246] The gap layer 17 and the upper shield 18 are formed on it. Moreover, although not illustrated, the Records department is further formed on it. As for the gap layer 17, NiFe which is used and has the thickness of 0.5-3 micrometers to the upper shield 18, Co system amorphous [ an alumina with a thickness of 5-100nm, nitriding aluminum, etc. ] magnetism alloy, a FeAlSi alloy, etc. are used.

0247] When the rule system alloy of face-centered tetragons, such as Mn rich alloy of gamma-Mn systems, such as Mn, RhMn, and RhRuMn, and PtMn, NiMn, is used as an antiferromagnetism layer 143 AuCu to which the ground layer 142 makes a principal component them, such as Cu, Ag, Pt, Au, Rh, Ir, and nickel The hcp phase metal which consists of alloys [ , such as Ru and Ti, ] which make them a principal component, such as alloys, such as CuCr, nickel of a Japanese Patent Application No. [ No. 229736 / nine to ] publication, nickel system alloy, NiFe, and a NiFe system alloy, is desirable.

0248] Moreover, although the ground layer mentioned above is sufficient as the ground layer 142 when using Cr system antiferromagnetism alloy film as an antiferromagnetism layer 143, the ground layer which consists of alloys

which make them a principal component, such as Cr, V, Fe, etc. which consist of a bcc layer, is also suitable.

[249] The magnetization fixing layer 144 consists of three layer membranes which consist of 1443 of 1441 of the ferro-layer ferromagnetic layer B combined in antiferromagnetism through the magnetic coupling layer 1442, and the ferromagnetic layer A. Since a big resistance change will be obtained if nonmetals, such as oxygen and nitrogen, are inserted in the middle of the ferromagnetic layer B and the antiferromagnetism layer 143, or the middle of the ferromagnetic layer B and the antiferromagnetism film of a vertical bias film, it is desirable. In this case, the layer thickness which inserts a nonmetal has desirable 0.2-2nm. For example, ferromagnetic layer A (or the ferromagnetic layer B) / oxidizing zone / ferromagnetic layer B (or the ferromagnetic layer A) which minded the oxidizing zone in the middle for the ferromagnetic layer A (or the ferromagnetic layer B) are desirable.

[250] The magnetic coupling layer 1442 has desirable Cr from which an antiferromagnetism joint function is obtained in the metal which consists of Ru, Rh, Ir, and Cr, Ru which has a big antiferromagnetism joint function especially, Ru which has an antiferromagnetism joint function in the latus thickness range, or the latus thickness range. It is usable if it is the thickness which can discover an antiferromagnetism joint function as shown in reference (Phy.Rev.Lett.67. 991) 3598) as thickness of a magnetic coupling layer.

[251] Residual magnetization ratio  $M_r/M_s$  shows Ru \*\* after heat treatment at the time of using Ru for the magnetic coupling layer of the ferromagnetic layer of Co, and the ferromagnetic layer of a CoFe alloy, and the relation of the fall degree of antiferromagnetism combination to drawing 21.  $M_r/M_s=1$  shows that antiferromagnetism combination is completely disappearance and antiferromagnetism combination with perfect  $M_r/M_s=0$  here.

[252] 1.2nm or less is desirable exceeding 0.8nm which does not produce property degradation of the magnetic coupling function by counter diffusion with the ferromagnetic layer B, and the ferromagnetic layer A and the magnetic coupling layer which adjoins even if it performs heat treatment at 250-300 degrees C which is needed at the head process of heat treatment or others of deciding the magnetization direction of the magnetization fixing layer 144 depending on the case when Ru is used for a magnetic coupling layer as shown in drawing 21 etc. Antiferromagnetism combination will become difficult, if Ru layer needs to pay attention for the fall of the antiferromagnetism joint function by counter diffusion in 0.8nm or less and exceeds 1.2nm \*\* on the other hand. Moreover, when Cr is used for magnetic coupling layer, 1.5nm or less is desirable at the same reason as the case where Ru is used, exceeding 0.8nm. And in the ferromagnetic layer B and the ferromagnetic layer A, Co or Co system alloy is desirable.

[253] If a  $\text{Co}_{1-x}\text{Fe}$  alloy ( $0 < x \leq 0.5$ ) is used for the ferromagnetic layer B and the ferromagnetic layer A, especially once a big switched connection coefficient with the antiferromagnetism layer 143 which consists of a Mn rich alloy of gamma-Mn systems, such as IrMn, RhMn, and RhRuMn, is obtained and diffusion with Ru, the ferromagnetic layer B, and the ferromagnetic layer A can moreover be prevented, it is desirable. In replacing with a CoFe alloy and using Co, compared with the case where 270 degrees C and the thickness range of the magnetic coupling layer which can maintain a stable magnetic coupling function also with heat treatment about maintenance for 1 hour are CoFe alloys as is about set to two thirds and it is shown in drawing 21, it becomes narrow.

[254] In addition, the surface smooth nature of a magnetic coupling layer is also important in order to maintain the thermal resistance of the antiferromagnetism joint function, and it is 2 10nm. Generating of the bigger surface regularity in the minute field in the film surface of a grade than the thickness of a magnetic coupling layer degrades the thermal resistance of an antiferromagnetism joint function. Therefore, as for the size of the surface irregularity of a magnetic coupling layer, it is desirable that it is below the thickness of a magnetic coupling layer.

[255] Change of the spin bulb film surface resistance  $R_s$  to the thickness of the ferromagnetic layer A and the ferromagnetic layer B, field resistance change  $\Delta R_s$ , and resistance rate-of-change  $\Delta R/R$  is shown in Table 9. Moreover, the change of resistance to the magnetic field of a spin bulb film is shown in drawing 22.

[256]

[table 4]

図 9

スピナル膜の構成:

Ta / Au / CuMn / 強磁性層 A (CoFe) / Ru (0.9 nm)

/ 強磁性層 B (CoFe) / Cu (2.5 nm) / 磁化自由層

(CoFe 4 nm) / Ta

処理: 270℃、1時間

強磁性層 A 厚さ (nm)	強磁性層 B 厚さ (nm)	抵抗変化率 $\Delta R/R$ (%)	表面抵抗値 $R_s$ ( $\Omega$ )	表面抵抗変化量 $\Delta R_s$ ( $\Omega$ )
7	7	7.2	7.5	0.54
5	5	8.0	9.8	0.78
3	3	8.6	12	1.03
2	2	8.4	14.1	1.18
1	1	8.0	15.3	1.22
0.5	0.5	5.9	15.6	0.92

ie external magnetic field with which the thickness of the ferromagnetic layer B and the ferromagnetic layer A was desirable in order to obtain resistance rate of change with big 1-5nm, and 1nm - 3nm thickness was especially indicated to be to drawing 22 from Table 9 -- receiving -- a stable (the falls of resistance are few even if it adds the external magnetic field of +600Oe) magnetization fixing layer -- in addition, especially since the strong spin bulb film surface resistance  $R_s$  is obtained and field resistance change  $\Delta R_s$  can also be satisfied, it is desirable Here, only by being large, since a reproduction output is proportional to the product of sense current and resistance change and resistance change is proportional to the product of field resistance of resistance rate of change and a spin bulb film, resistance rate of change cannot obtain high power, when field resistance is small. That is, in order to obtain high power, high field resistance is required with high resistance rate of change.

図 257] Drawing 23 is drawing showing the resistance change by the magnetic field at the time of setting thickness of the ferromagnetic layer A constant 3nm, and changing the thickness of the ferromagnetic layer B.

図 258] If magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is made equal so that drawing 3 may see, change of resistance by the high magnetic field of +600Oe is small, therefore a remarkable stable magnetization fixing layer can be realized to a medium magnetic field, the magnetic field from a vertical bias layer, the external magnetic field at the time of the Records Department formation heat treatment, etc. Moreover, the problem of the flux reversal of the magnetization fixing layer by ESD is current by the circuit which compensates the fixing magnetization direction included in the drive, as already stated, and it can respond by returning the magnetization direction towards desired.

図 259] On the other hand, the following advantages are acquired by changing the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B. Operation of magnetization fixing by heat treatment for making the 1st and magnetization of the magnetization free layer which is the fundamental composition of a spin bulb, and a magnetization fixing layer cross at right angles first becomes easy. Higher resistance rate of change is obtained by making magnetic thickness of the ferromagnetic layer B smaller than the magnetic thickness of the ferromagnetic layer A, by the table 10 showing the relation between the thickness of the ferromagnetic layer B, and resistance rate of change in the 2nd, so that clearly. The flux reversal of the magnetization fixing layer by ESD will hardly happen 3rd ], and a stable reproduction output is obtained to near the breakdown voltage. It is the voltage on which a spin bulb element destroys breakdown voltage with voltage here, and spin bulb element resistance begins to increase.

図 260]

Table 5]

図 10

スピナル膜の構成:

Ta (5 nm) / AuCu (2 nm) / CoFe (5 nm) / Cu (3 nm)

/ 強磁性層 A (CoFe) / Ru (0.9 nm) / 強磁性層 B (CoFe)

/ IrMn (10 nm) / Ta (5 nm)

強磁性層 A 厚さ (nm)	強磁性層 B 厚さ (nm)	抵抗変化率 $\Delta R/R$ (%)
3	3	7.3
3	2.5	7.8
3	2	7.7

For example, when the ratio of the magnetic thickness of the ferromagnetic layer B and the ferromagnetic layer A is set to the ferromagnetic layer A, the ferromagnetic layer B, and a magnetization free layer 0.7-0.9 when Co, CoFe, and NiFe are used, respectively and Cu is used for a nonmagnetic interlayer, and the thickness of the ferromagnetic layer B is set as 2.5nm, a good ESD property as shown in drawing 24 , drawing 25 , and Table 11 can be acquired. Resistance and an output after drawing 24 and drawing 25 give the ESD voltage of the simulation by the human body model to a spin bulb element here are shown, and drawing 24 shows the case where the magnetic thickness of drawing 25 of the ferromagnetic layer A is larger than the magnetic thickness of the ferromagnetic layer B, when the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is equal. Moreover, Table 11 shows the ESD property by the test pattern to a spin bulb element.

[261]

Table 6]

11

ピンバルブ膜構成:

Ta (5nm) / 磁化自由層 / Cu (3nm) / 強磁性層A / Ru (0.9nm)

/ 強磁性層B / IrMn (10nm) / Ta (5nm)

子構成: バターンニング無しの下シールド、下キャップ上に形成したCoPt/FeCo

下地ハード膜縦バイアスおよび電極が縦バイアス間隔よりも狭いリードオーバーレ

イドを用いた構造 (シールドは無し)。

電極間隔=1.3μm

磁気膜厚比 $(M_s \cdot t) A / (M_s \cdot t) B$	強磁性層A	強磁性層B	磁化自由層	固定磁化 反転電圧	ブレーク ダウン電圧
0.75	CoFe(2nm)	CoFe(1.5nm)	CoFe(3nm)/NiFe(1.5nm)	反転せず	70V
0.8	CoFe(2.5nm)	CoFe(2nm)	CoFe(3nm)/NiFe(1.5nm)	反転せず	75V
0.83	CoFe(3nm)	CoFe(2.5nm)	CoFe(4nm)/NiFe(1.8nm)	反転せず	70V
0.85	Co(2nm)	Co(1.7nm)	Co(0.5nm)/NiFe(4nm)	反転せず	70V
0.71	CoFe(2.4nm)	CoFe(1.7nm)	CoFe(1nm)/NiFe(3nm)	65V	75V
0.88	CoFe(2.4nm)	CoFe(2.1nm)	CoFe(1nm)/NiFe(3nm)	65V	75V
1	CoFe(3nm)	CoFe(3nm)	CoFe(4nm)/NiFe(1.8nm)	50V	75V
0.667	CoFe(3nm)	CoFe(2nm)	CoFe(3nm)/NiFe(1.5nm)	55V	75V
0.93	CoFe(3nm)	CoFe(2.8nm)	CoFe(1nm)/NiFe(3nm)	55V	70V

Although the magnetic field which is mainly concerned with a current magnetic field in a magnetization fixing layer at the time of ESD generating is strongly added [ rather than ] to the ferromagnetic layer A to the ferromagnetic layer B, this is The ratio of the current magnetic field, and  $H(\text{current}) B / H(\text{current}) A$  Since it is mostly in agreement with the reciprocal ratio of magnetic thickness, and  $A (M_s \cdot t) / (M_s \cdot t) B$  The variation of the energy of the magnetization and external magnetic field of the ferromagnetic layer A and the ferromagnetic layer B offsets each other. It is because the energy change as the whole and  $\{(M_s \cdot t) - H(\text{current})\} A - \{(M_s \cdot t) H(\text{current})\} B$  can realize a small state and, as a result, cannot move magnetization of a magnetization fixing layer by the ESD current magnetic field.

[262] When the ferromagnetic layer A is 2nm as shown in drawing 23 , therefore  $(M_s \cdot t) 3nm$  and the ferromagnetic layer B are set to  $B / (M_s \cdot t) A = 0.67$ , they compare the ferromagnetic layer A and the ferromagnetic layer B with the case of this 3nm drawing (a), and it is HUA\*. It falls, therefore the thermal resistance of a magnetization fixing layer also falls. Thus, when magnetic thickness of the ferromagnetic layer B is made smaller than the ferromagnetic layer A, it is desirable to choose the energization direction of sense current so that the magnetic field from sense current may be added in the same direction (namely, the same direction as magnetization of the ferromagnetic layer B) as the bias magnetic field from the antiferromagnetism layer which joins the ferromagnetic layer B. Since the disclosure magnetic field by which it is equivalent to the magnetic thickness difference of the ferromagnetic layer A and the ferromagnetic layer B like the spin bulb film of the magnetization fixing layer of the conventional monolayer when the direction of the ferromagnetic layer A has magnetic large thickness joins a magnetization free layer, the reason Although magnetization rectangular cross arrangement with a magnetization free layer and a magnetization fixing layer is disturbed and the fall of a reproduction output produces the problem of the vertical asymmetry of a reproduction wave increasing This disclosure magnetic field can be offset by passing sense current so that the magnetic field by sense current may be added in an exchange bias magnetic field and this direction, as shown in drawing 26 which shows the magnetization and disclosure magnetic field in a spin bulb.

[263] It is desirable to use for a nonmagnetic interlayer the alloy which makes a principal component Cu, Au, Ag imple substance, or them. Although it can be fundamentally used if it is about 1-10nm which is the range which can

tain resistance rate of change, especially since the ferromagnetic-like joint magnetic field which the thickness range of 1.5nm - 2.5nm generates between a magnetization fixing layer and a magnetization free layer can be suppressed to 5 or less Oes and high resistance rate of change is especially obtained by the spin bulb film of this invention, the thickness is desirable.

[264] The NiFe alloy which minded [ Co alloy /, such as Co, CoFe, CoNi, and CoFeNi, /, NiFe alloy, or those dominating composition, for example, interlayer, ] 0.3-1.5nm thin Co is used for a magnetization free layer. And the thickness of a magnetization free layer has desirable 1-10nm.

[265] Table 12 is a table in which having set the thickness of a magnetization fixing layer (magnetization fixing layer) constant 2.5nm, and having shown the relation between the thickness of a magnetization free layer, and resistance rate-of-change  $\Delta R/R$ . As shown in Table 10, in this invention, magnetization free thickness is desirable, especially in order that 2-5nm may obtain high resistance rate of change.

[266]

[Table 7]

Table 12

磁化自由層 厚さ (nm)	強磁性層 A = 強磁性層 B 厚さ (nm)	抵抗変化率 $\Delta R/R$ * 磁化自由層が CoFe 単層 (%)	抵抗変化率 $\Delta R/R$ ** 磁化自由層が中間層後に 1nm Co をはさんだ NiFe (%)
1	2.5	6.2	5.7
2	2.5	7.5	7.0
3	2.5	7.9	7.2
4	2.5	7.8	7.2
5	2.5	7.5	7.1
6	2.5	6.9	6.4
7	2.5	6.6	6.0

強磁性層 A と強磁性層 B は同じ厚さで CoFe 合金を用いた。

Table 13 is a table in which having set magnetization free layer thickness constant 4nm, and having shown the relation between the thickness of the ferromagnetic layer A of a magnetization fixing layer, and resistance rate-of-change  $\Delta R/R$ . As shown in Table 11, it is desirable to have the relation of  $-0.33 \leq \{t(F)-t(P)\}/t(F) \leq 0.67$  between thickness [ of a 2-5nm magnetization free layer ]  $t(F)$  and thickness [ of the ferromagnetic layer A ]  $t(P)$  in order to obtain high resistance rate of change.

[267]

[Table 8]

Table 13

磁化自由層厚さ $t(F)$ (nm)	強磁性層 A 厚さ $t(P)$ (nm)	抵抗変化率 $\Delta R/R$ (%)	$(t(F) - t(P)) / t(P)$
4.5	1	4.7	0.78
4.5	1.5	6.9	0.67
4.5	2	7.1	0.56
4.5	3	7.9	0.33
4.5	4	7.7	0.11
4.5	5	7.3	-0.11
4.5	6	6.8	-0.33
4.5	7	5.9	-0.66

磁化自由層は CoFe 合金

強磁性層 A と強磁性層 B は CoFe 合金

強磁性層 B の厚さは 3 nm

metals, such as Ta, Nb, Zr, Cr, Hf, Ti, Mo, and W, those alloys or the oxide of these metals, a nitride, etc. are used for protective coat. It is desirable in order that protective coats of high resistance, such as a NiFe oxide, nitriding aluminum, and a tantalum acid ghost, may especially obtain high resistance rate of change by the oxide or the nitride, for example. Since removal by etching of a protective coat becomes easy when forming the electrode and vertical bias layer which a thing thin as much as possible describes as 0.3-4nm later, the thickness is desirable. Moreover, in the

use of for example, a CoFe magnetization free layer, in the case of a NiFe magnetization free layer, Cu/Ru, Cu and Ru, Cu alloy, etc. may use a noble-metals simple substance, an alloy monolayer, or layered products, such as Ag, Au, Pt, Ir, Cu, Pt, Pd, and Re, for Ag, Ru, Ru/Ag, Ru/Cu, Cu, etc. at a protective coat. You may form high resistance protective coats, such as Ta, further on an oxide, a nitride, and a noble-metals protective coat.

0268] Making magnetization of a magnetization fixing layer and a magnetization free layer intersect perpendicularly can be carried out by the following method. That is, after carrying out in the magnetic field to which the antiferromagnetism layer 143 impressed membrane formation to the magnetic coupling layer 1442 in the cross direction, i.e., height direction, of a spin bulb element when forming a spin bulb in the case of Mn rich alloy of gamma-Mn systems, such as IrMn, RhMn, and RhRuMn, it heat-treats in order to, arrange the direction of a switched connection bias magnetic field of the antiferromagnetism layer 143 with \*\* on the other hand. In addition, it is more desirable for magnetic coupling layers, such as Ru, to form membranes to 1442 layers of magnetic coupling layers, since it is more strong to oxidization, although \*\*\*\*\* [ heat treatment for on the other hand arranging the direction of switched connection bias magnetic field of this antiferromagnetism layer 143 with \*\* / immediately after membrane formation of the ferromagnetic layer B ]. It is desirable in a vacuum a short time and to carry out preferably at temperature higher than  $T_b$  in a short time for 10 or less minutes and the magnetic field with which the ferromagnetic layer B is saturated completely, without this heat treatment carrying out leak after membrane formation. For example, it carries out about 1 minute at 350 degrees C at IrMn which is 300 degrees C.

0269] Next, without leaking, at least during magnetic free layer membrane formation, a magnetic field is added in the direction of the width of recording track of a spin bulb element, and a subsequent spin bulb element is formed. Although the case of the rule combination gold of PtMn or NiMn also has the same antiferromagnetism layer 143 -- the antiferromagnetism layer of a gamma-Mn system -- differing -- not necessarily -- the membrane formation to the ferromagnetic layer B -- the inside of a magnetic field -- it is not necessary to carry out -- subsequent heat treatment -- the elevated temperature of 200 degrees C or more -- it is necessary to carry out preferably at 270-350 degrees C for 1 to 20 hours for several hours After heat treatment gives a magnetic field during membrane formation of a magnetization free layer similarly, and performs subsequent spin bulb membrane formation.

0270] In addition, any antiferromagnetism layer can also perform heat treatment in spin bulb membrane formation after spin bulb membrane formation. In this case, it is desirable to add the magnetic field exceeding the joint magnetic field of the magnetic coupling layer 1442, to saturate completely magnetization of the ferromagnetic layer A and the ferromagnetic layer B in this direction (the height direction), and to heat-treat. For example, the magnetic field which ferromagnetic layer B / magnetic coupling layer / ferromagnetic layer A adds during heat treatment since the joint magnetic fields of Ru are about 6 kOe(s) in CoFe2 nm/Ru0.9 nm/CoFe2nm has 7 or more desirable kOes. In order to make small the magnetic field added at the time of this heat treatment, it is desirable to heat-treat, before processing a spin bulb film into an element configuration. After processing, since [ of an anti-magnetic field ] it is based on an element configuration, a strong magnetic field is needed saturating the ferromagnetic layer A and the ferromagnetic layer B.

0271] Magnetization of the magnetization fixing layer 144 is made to fix towards desired by the above method. However, when the above-mentioned heat treatment is strong, it becomes difficult for the magnetization free layer 146 and the easy axis of the lower shield 11 to make it intersect perpendicularly with magnetization of a magnetization fixing layer toward the height direction of a spin bulb element like a magnetization fixing layer. In order to turn a magnetization free layer and the easy axis of a lower shield in the direction of the width of recording track, in the resist ure process in a recording head, it is desirable to add the degree about magnetic field of necessary minimum with which a shield and a magnetization free layer are saturated in the direction of the width of recording track, for example, 100-300 Oes, and to stabilize the easy axis of a shield or a magnetization free layer in the direction of the width of recording track. Moreover, as for a lower shield, it is desirable to stabilize an easy axis in the direction of the width of recording track with heat treatment beforehand before spin bulb membrane formation.

0272] What CoPt, CoPtCr, etc. which were formed on grounds, such as a hard magnetic film, for example, Cr, and CrCo, carried out the laminating of the ferromagnetism layer 151 and the antiferromagnetism layer 152 to the vertical bias layer one by one, and made the ferromagnetic layer hard is used with the element structure of the ABATTOJI cushion type shown in drawing 17, i.e., the element structure which removed the width-of-recording-track edge of a magnetization free layer, and formed the vertical bias layer there. The antiferromagnetism layer 152 may be formed first and, next, the ferromagnetic layer 151 may be formed. The magnetic thickness ratio of the ferromagnetic layer by which switched connection bias was carried out by the vertical bias ferromagnetism layer to a magnetization free layer, i.e., a hard magnetic layer, and the antiferromagnetism film in order to have obtained the steep reproduction sensitivity profile in a width-of-recording-track edge corresponding to the future \*\* truck, and LB (Ms-t)/(Ms-t) F Setting or less or two is desirable. If a magnetization free layer becomes thin to about 3-6 nmTs by 2-5nm \*\* or magnetic thickness, it

LB (Ms-t)/(Ms-t) F. In order to carry out to two or less, a vertical bias ferromagnetism layer also becomes very thin, for example, it is set to 12 or less nmT by magnetic thickness.

[273] However, generally, by the hard magnetic film, if it becomes thin to 10nm thick intensity, high coercive force will become difficult to get. For example, what was the high coercive force of 2000Oe in the CoPt hard magnetic film whose Ms is 1T at 20nm \*\* falls to 800Oe(s) in 10nm. On the other hand, in a ferromagnetic / antiferromagnetism film type vertical bias layer, an exchange bias magnetic field increases and fixing becomes firm, so that a ferromagnetic 151 becomes thin. For example, the coercive force which was 80Oe(s) at 20nm \*\* in the vertical bias layer which carried out the laminating of the IrMn of NiFe whose Ms is 1T, and 7nm \*\* increases even to 160Oe(s) in 10nm \*\*. These 60Oe(s) are values which have an actual result by the conventional MR head. Therefore, it is desirable to use a ferromagnetic / antiferromagnetism film type vertical bias layer in the field where magnetization free layer thickness is very thin, for example, a field in which it becomes 5nm thick less or equal.

[274] Furthermore, it is desirable when it fully removes a Barkhausen noise in the vertical bias layer of ferromagnetic 151 / antiferromagnetism film 152 that the saturation magnetization of a ferromagnetic 151 is almost equal to the saturation magnetization of a magnetization free layer, or it is larger than it by as small the vertical bias magnetic field as possible. That is, although a NiFe alloy is sufficient as a ferromagnetic 151, a NiFeCo alloy with more large saturation magnetization, a CoFe alloy, Co, etc. are more desirable. If a disclosure magnetic field is strengthened, a Barkhausen noise is removed by enlarging the thickness using the small film of saturation magnetization as a ferromagnetic 151 and it will become the narrow width of recording track especially, the fall of a reproduction output will be caused.

[275] In addition, although the case where a vertical bias layer was formed was shown by drawing 17 without removing all spin bulb films, you may carry out etching removal to the ground layer 141. However, in order to keep the crystallinity of a ferromagnetic layer good, it is desirable to leave the ground layer 142 at least and to use the crystalline improvement effect as the depth in which it \*\*\*\*\*s before forming a vertical bias layer. From a viewpoint of a thickness control, it is desirable to \*\*\*\*\* the thicker antiferromagnetism layer 143 a little, to weaken the exchange bar chair, and to obtain the vertical bias layer of a good hard film property. You may give the vertical bias layer which ends etching to a nonmagnetic interlayer's middle and consists of a 151/antiferromagnetism film 152 of ferromagnetics on it. In addition, in order [ for a crystalline improvement ] to weaken the magnetic coupling of a magnetization fixing layer, the antiferromagnetism layer 143, and a vertical bias layer, you may form the very thin ground layer 153 as well as the ground layer 143 in the bottom of a ferromagnetic 151. In order to stop reduction of the magnetic coupling of a magnetization free layer and a vertical bias layer to the minimum, the thickness of the ground layer 153 has desirable 10nm or less.

[276] When using a hard magnetic film, it is desirable to arrange the saturation magnetization of a magnetization free layer and a hard magnetic film similarly. However, it is usually difficult to produce the hard magnetic film of the high saturation magnetization which is equal to high saturation magnetization free layers, such as CoFe. Then, the method of maintaining balance with saturation magnetization with a magnetization free layer is suitable for removing a Barkhausen noise by the small vertical bias magnetic field using the film of high saturation magnetization like FeCo as a ground of a hard magnetic film.

[277] The same antiferromagnetic substance as what was used for the spin bulb film can be used for the antiferromagnetism film 152. However, the exchange bias magnetic field of the height direction and the antiferromagnetism film 152 of a vertical bias layer needs to make the direction of the width of recording track, and the exchange bias magnetic field of the antiferromagnetism layer of a spin bulb cross at right angles mutually. Then, after for example, ] heat treatment prescribes the direction of an exchange bias magnetic field of the antiferromagnetism layer which both blocking temperature Tb is changed and has high Tb first, A mutual exchange bias magnetic field can be made to intersect perpendicularly by setting up the direction of an exchange bias magnetic field of the antiferromagnetism film which has low Tb, heat-treating low temperature more to the antiferromagnetism film which has Tb lower than it, and keeping stable the direction of exchange bias of a high Tb antiferromagnetism layer.

[278] On the antiferromagnetism film 152, specifically with heat treatment of PtMn, PdPtMn, etc. Although the antiferromagnetism film which discovers HUA is sufficient, Tb which a magnetization fixing layer can heat-treat at stable temperature is 200-300 degrees C. If the antiferromagnetic substance with Tb higher than it, i.e., IrMn, PtMn, tPdMn, etc. are used for the antiferromagnetism layer of a spin bulb film, RhMn, IrMn, RhRuMn, FeMn, etc. The direction of exchange bias of the antiferromagnetism film 152 can be specified in the direction of the width of recording track, without disturbing the direction of magnetization fixing layer magnetization of a spin bulb film at the assist cure heat treatment process mentioned above. That is, \*\*\*\* can make vertical bias and magnetization fixing layer magnetization intersect perpendicularly good, even if the blocking temperature gradient between both antiferromagnetism films is dozens of degrees C by using the property which pin magnetization stabilizes rapidly

elow at the blocking temperature which is the feature of this invention. When IrMn, FeMn, RhMn, RhRuMn, rMnPt, CrMn, etc. which can give an exchange bias magnetic field to the antiferromagnetism film 152 by membrane formation among a magnetic field are used, heat treatment moreover, to eye an unnecessary hatchet No matter what layer [ antiferromagnetism ] the direction of a bias magnetic field of the antiferromagnetism layer 143 of a spin bulb film may not be disturbed and it may use for the antiferromagnetism layer 143 of a spin bulb film, the direction of vertical bias and the magnetization fixing layer magnetization direction can be made to intersect perpendicularly.

0279] On the other hand, as shown in drawing 27 , vertical bias can be added to a magnetization free layer also with the structure which carried out etching removal only of the protective coat 147 of the width-of-recording-track edge of magnetization free layer, and carried out the switched connection laminating of the antiferromagnetism film on it. As for the vertical bias layer 15, it is desirable to mind the buffer layer 1511 for strengthening switched connection with a magnetization free layer as the antiferromagnetism layer 152 and its ground. As for this buffer layer 1511, it is desirable that it is the ferromagnetic layer which consists of Fe, Co, nickel, etc. The convention of the magnetization direction of vertical bias is the same as that of the case of the vertical bias of the 151/antiferromagnetism layer 152 of ferromagnetic layers. The vertical bias method using the antiferromagnetism layer has the advantage which can suppress a Barkhausen noise, without generating an excessive vertical bias magnetic field like a hard magnetic-film method, and causing the sensitivity fall of a head.

0280] (Form 3 of operation) The 3rd operation form of this invention is shown in drawing 28 . As for drawing 28 , the structure of a spin bulb film differs from drawing 21 . In drawing 27 , the spin bulb film 14 formed on the lower gap 12 of Ta, Nb, Zr, The nonmagnetic ground layer 141 with a thickness [ , such as Hf, ] of 1-10nm, It consists of protective coats 147 with a thickness of 0.5-10nm the 2nd ground layer 142 with a thickness of 0.5-5nm, the magnetization free layer 146, the interlayer 145 with a thickness of 0.5-4nm, the magnetization fixing layer 144, the antiferromagnetism layer 143, and if needed if needed. The magnetization free layer (free layer) 146, an interlayer 145, the magnetization fixing layer 144, and the antiferromagnetism layer 143 are the same composition as the operation form 2 here.

0281] When the alloy which makes a principal component Au, Cu, Ru, Cr, nickel, Ag, Pt, Rh, or them was used and a CoFe alloy is used especially for a magnetization free layer, the thermal resistance of resistance rate of change can be used to the ground layer 142.

0282] In drawing 27 , the spin bulb element 13 is constituted by the same vertical bias layer 15 of a couple as drawing 1 , and the electrode 16 of a couple together with the spin bulb 14. The upper gap layer 17 and the upper shield 18 are constituted still like drawing 21 on it.

0283] (Form 4 of operation) Drawing 29 is the operation form of further others of this invention, and shows the example at the time of applying this invention to dual type spin bulb structure.

0284] In drawing 29 , like the case of drawing 21 of the operation form 2, and drawing 27 of the operation form 3, the vertical bias layer 15 of a couple, the electrode 16 of a couple, the vertical bias layer 15, and the spin bulb element 13 that consists of a spin bulb film 14 are formed on the lower shield 11 and the lower gap 12, and the upper gap 17 and the upper shield 18 are formed on it. However, the interval of an electrode 16 and the composition of the spin bulb film 4 differ from drawing 21 and drawing 27 .

0285] The spin bulb film 14 Ta, Nb, Zr, The nonmagnetic ground layer 141 with a thickness [ , such as Hf, ] of 1-10nm and the need are accepted. The 2nd ground layer 142 with a thickness of 0.5-5nm, the antiferromagnetism layer 143, the magnetization fixing layer 144, the interlayer 145 with a thickness of 0.5-4nm, the magnetization free layer 146, the 2nd interlayer 148 with a thickness of 0.5-4nm, It consists of protective coats 147 with a thickness of 0.5-10nm the 2nd magnetization fixing layer 149, the 2nd antiferromagnetism layer 150, and if needed.

0286] The laminating magnetization fixing layer which becomes at least one side of the magnetization fixing layer 144 and the magnetization fixing layer 149 from the same ferromagnetic layer A and same magnetic coupling layer as drawing 17 , and the ferromagnetic layer B is used. the combination of the monolayer magnetization fixing layer of the former [ layer / 1 magnetization fixing / 149 / layer / magnetization fixing / 144 / a SyAF magnetization fixing layer and ] and 2 -- to the magnetization fixing layer 144, the combination of a SyAF magnetization fixing layer can be conversely used in a SyAF magnetization fixing layer and the magnetization fixing layer 149 in the combination of the conventional monolayer magnetization fixing layer, or the both sides of 3 magnetization fixing layer 149 and the magnetization fixing layer 144 / and

0287] Although the vertical bias layer 15 is the so-called ABATTO junction type of element structure After using the same vertical bias layer 15 as drawing 17 , drawing 27 , and drawing 28 into the lift-off method, using a photoresist as mask and carrying out etching removal of the width-of-recording-track edge of a spin bulb film, by methods, such as sputter, vacuum evaporation, and ion beam membrane formation forming the vertical bias layer 15 -- facing -- etching removal of the spin bulb film 14 -- at least -- the conductor layer of the spin bulb film 14 -- \*\*\*\*\* -- it is desirable to carry out like For example, when the antiferromagnetism layer 143 is a gamma-Mn system alloy like IrMn,

is desirable to leave a part of antiferromagnetism layer 143 at least.

[288] If it leaves the conductor section to a width-of-recording-track edge, since the contact resistance of an ABATTO junction will fall, it is easy to realize the spin bulb element 13 of low resistance, and, for this reason, a long head can be realized to static electricity. Of course, etching removal of all the spin bulb films of a width-of-recording-track edge may be carried out, and a vertical bias layer may be formed.

[289] Although an electrode 16 may be put in block with a vertical bias layer and lift-off formation may be carried out, an electrode spacing and the interval of a vertical bias layer are mostly in agreement in this case. Or it is good also for the so-called lead exaggerated RAID structure which separated electrode formation with vertical bias layer formation, and narrowed and formed the electrode spacing from the interval of a vertical bias layer. When it was lead exaggerated RAID structure and a hard magnetic layer is used especially for a vertical bias layer, the influence of the disclosure magnetic field from a hard magnetic layer can be shut up near [ where the laminating of the spin bulb film is carried out to the electrode ] the width-of-recording-track edge section, and there is a merit which can be specified to the sensitivity profile sharp of the direction of the width of recording track of the regenerative-track width of face specified by inter-electrode with high degree of accuracy. In high-density record to which especially regenerative-track width of face serves as submicron one, the merit becomes clearer compared with the conventional method. Naturally this lead exaggerated RAID structure is applicable also to the operation form of drawing 21 or drawing 27.

[290] (Form 5 of operation) Drawing 30 is the operation form of further others of this invention. Like the form 2 of operation shown in drawing 21, a lower shield and a lower cap (not shown) are formed on a substrate (not shown), the spin bulb film 13 is further formed on it, and although not further illustrated on it, an upper cap, an upper shield, and the Records Department are formed. The vertical bias layer 15 and electrode 16 of a couple are formed in the width-of-recording-track ends of the spin bulb film 13. The case where the layered product which consists of the ground layer 153, a ferromagnetic 151, and an antiferromagnetism film 152 was used for a vertical bias layer as an example was shown. Naturally hard magnetic films, such as CoPt, can be used for a vertical bias layer.

[291] An electrode 16 forms low resistance metals, such as Ta/Au/Ta, using the material included at least, an electrode spacing LD is formed more narrowly than the vertical bias interlayer spacing HMD, and the spin bulb film 13 and an electrode 16 have the field which carries out field contact near the width-of-recording-track ends. Although a vertical bias layer and an electrode are usually formed of a lift off, you may form them by the ion milling method, the reactive-ion-etching method, etc. Although a process process becomes complicated, a drive process is especially suitable for highly precise electrode formation.

[292] In spin bulb film 13 field of electrode 16 directly under in which the vertical bias layer 15 does not exist The resistance of an electrode compares with the resistance of a spin bulb film. when small enough, to the case of 1/10 or less If magnetization of the magnetization free layer 146 of a spin bulb film is mostly specified in the direction of the width of recording track when a medium magnetic field is zero mostly, since reproduction sensitivity will furthermore be reduced sharply in parts other than inter-electrode [ , such as directly under / of a spin bulb film / electrode / , ] An electrode spacing LD can prescribe regenerative-track width of face, and the steep reproduction sensitivity distribution at a width-of-recording-track edge can be realized.

[293] Since a field surface of action can furthermore take the spin bulb film 13 and the sufficiently large electrode 16 compared with the usual ABATTO junction method, the contact resistance of an electrode and a spin bulb can control small enough, as a result, the spin bulb element of low resistance can be realized, and, moreover, a magnetoresistance-effect head strong against ESD can be realized in a low noise.

[294] In order to raise recording density here from now on and to narrow regenerative-track width of face, it is necessary to narrow an electrode spacing LD. On the other hand, if an electrode spacing becomes remarkably narrow, it will become difficult to narrow the width of face of an element, i.e., height, more than it. Therefore, it is desirable to make HD larger than LD when manufacturing a head with the sufficient yield. Specifically, in order to keep good the field at the time of head mass production, about the height which determines a size with machining, about 0.5 micrometers and more than it are required, and when regenerative-track width of face narrows in 0.5 micrometers or less, it is desirable to set up HD more greatly than LD. However, the following problems occur in that case.

[295] The 1st problem is that a reproduction output decreases, in order that resistance of the reproduced spin bulb film field may decrease. It was avoided by raising field resistance of a spin bulb film to this problem. Although it was difficult to obtain high field resistance since fixing thickness was conventionally thicker than the magnetization fixing layer of a monolayer, as shown in Table 14 and 15, by this invention, it is compatible in high field resistance of 5ohms or more, and 8% or more of high resistance change with the usual SyAF fixing layer by suppressing the sum total of the thickness of the thickness of a magnetization fixing layer, a nonmagnetic interlayer, and a magnetization free layer to 14nm thick less or equal.

[296]

able 9]

14

ピンバルブ膜構成: Ta (5nm)/Au (2nm) / IrMn (7nm)/強磁性層 B/ 磁化結合層/ 強磁性層 A/ 中間非磁性層/ 磁化自由層/ Ta

強磁性層 B 厚さ (nm)	磁化結合層 厚さ (nm)	強磁性層 A 厚さ (nm)	非磁性中間 層厚さ (nm)	磁化自由層 厚さ (nm)	強磁性層 B~磁化自 由層合計厚さ (nm)	R <sub>s</sub> (Ω)	ΔR/R (%)
CoFe (3nm)	Ru (0.9nm)	CoFe (3nm)	Cu (2nm)	CoFe (0.5nm)/NiFe (1.5nm)	9.9	33.5	8.3
CoFe (1.5nm)	Ru (0.8nm)	CoFe (2nm)	Cu (2nm)	CoFe (0.5nm)/NiFe (4nm)	10.8	19.5	8.7
CoFe (1.5nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (3nm)	9.9	19.5	9.7
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2nm)	Co (1nm)/NiFe (5nm)	12.9	18.2	8.9
CoFe (1.5nm)	Ru (0.9nm)	CoFe (1.5nm)	Cu (2nm)	Co (1nm)/NiFe (3nm)	9.9	22.8	8.1
CoFe (2nm)	Ru (0.9nm)	CoFe (2.5nm)	Cu (2nm)	CoFe (3nm)	10.4	19.4	10.7
CoFe (2nm)	Ru (1nm)	CoFe (2.5nm)	Cu (2.5nm)	Co (1nm)/NiFe (4nm)	13	18	8.1
CoFe (2.2nm)	Ru (0.8nm)	CoFe (2.5nm)	Cu (2nm)	CoFe (2nm)/NiFe (4.5nm)	14	16	8.7
CoFe (3nm)	Ru (0.9nm)	CoFe (3nm)	Cu (3nm)	CoFe (1nm)/NiFe (7nm)	17.8	13	6.5
CoFe (3nm)	Ru (0.9nm)	CoFe (3nm)	Cu (3nm)	CoFe (3nm)/NiFe (2nm)	14.8	12	7.2
CoFe (2.5nm)	Ru (0.8nm)	CoFe (3nm)	Cu (2.5nm)	CoFe (1nm)/NiFe (7nm)	16.8	14.7	7.3
CoFe (3nm)	Ru (0.7nm)	CoFe (3nm)	Cu (3nm)	CoFe (5nm)	14.7	12.5	8.2

297]

able 10]

15

ピンバルブ膜構成: Ta (5nm)/NiFe (2nm) PtMn (7.5nm)/強磁性層 B/ 磁化結合層/ 強磁性層 A/ 中間非磁性層/ 磁化自由層/ Ta

強磁性層 B 厚さ (nm)	磁化結合層 厚さ (nm)	強磁性層 A 厚さ (nm)	非磁性中間層 厚さ (nm)	磁化自由層 厚さ (nm)	強磁性層 B~磁化自 由層合計厚さ (nm)	R <sub>s</sub> (Ω)	ΔR/R (%)
Co (2nm)	Ru (0.9nm)	Co (2nm)	Cu (2.5nm)	Co (1nm)/NiFe (2nm)	10.4	23.5	18.5
Co (2nm)	Ru (0.9nm)	Co (2nm)	Cu (2.5nm)	Co (0.5nm)/NiFe (2nm)	9.9	19.7	7.9
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (1nm)/NiFe (2nm)	9.7	18.6	8.7
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (3nm)	10.4	18.3	9.1

[298] In order to realize high resistance rate of change using such an ultra-thin spin bulb film 1) CoFe with a stable c phase, CoNi, and a CoFeNi alloy are used for the ferromagnetic layer A of a magnetization fixing layer, and the ferromagnetic layer B, 2) Co, CoFe, CoNi, and a CoFeNi alloy are used also for a magnetization free layer at least near the interface with a middle non-magnetic layer, 3) It is desirable to use the antiferromagnetism layer containing noble metal elements, such as PtMn, PtPdMn, IrMn, RhMn, and RhRuMn, for an antiferromagnetism film.

[299] The 2nd problem in the case of setting up HD more greatly than LD is generating of a Barkhausen noise. With the spin bulb element of the ABATTO junction method the conventional electrode spacing and whose interval HMD of vertical bias film correspond mostly, HMD becomes smaller than HD, the direction of HD becomes a long rectangle configuration, magnetization of a magnetization free layer becomes easy to turn to the configuration of a magnetization free layer in the height direction where an anti-magnetic field is weak, and, as a result, a Barkhausen noise generates it. On the other hand, in this invention, the configuration of a spin bulb film does not say that it becomes easy to turn to magnetization of a magnetization free layer in the height direction since HMD is more greatly [ than HD ] long in the direction of the width of recording track, and for this reason, removal of a Barkhausen noise is easy and can improve head manufacture ] the yield about this point.

[300] As an example, it is 1HD=0.5micrometer, LD=0.45micrometer, HMD=1.3micrometer, 2HD=0.4micrometer, D=0.35micrometer, HMD=0.8micrometer, etc., and is a book.

[301] In addition, although the case where the magnetization fixing layer had been arranged between a magnetization free layer and a substrate was shown in drawing 29 , it is applicable similarly about the case where a magnetization

se layer exists between a substrate and a magnetization fixing layer.

302] (Form 6 of operation) The form of the operation of further others of this invention is shown in drawing 31. The substrate which is not illustrated, a lower shield, and a lower gap are formed, and the vertical bias layer 15 of a couple formed on it of dry processes, such as the lift-off method, ion milling, and reactive ion etching. Although the case here it consisted that the form 2 of operation showed drawing 29 as an example of a vertical bias layer of a layered product of the ferromagnetics 151, such as the antiferromagnetism films 152, such as the ground layer 153 and IrMn suitable for the same antiferromagnetism layer, RhMn, and CrMn, CoFe, NiFe, and Co, was shown, each of other vertical bias layer shown with the form 2 of operation is applicable.

303] Besides, the spin bulb film 13 is formed. In order to give the bias magnetic field from a vertical bias layer effectively to the magnetization free layer 143, as for the spin bulb film 13, it is more more desirable than a magnetization fixing layer that the vertical bias layer 15 and the magnetization free layer 143 make it easy to arrange the magnetization free layer 143 and to approach a substrate side. In order to give the bias magnetic field from a vertical bias layer effectively to a magnetization free layer, as for the thickness of the ground layers 141 and 142 of the magnetization free layer 143, it is desirable that it is 10nm. Moreover, the field surface of action of the spin bulb film 13 and the vertical bias 15 is desirable when making it small as much as possible suppresses a Barkhausen noise.

304] On the spin bulb 13, the electrode 16 of a couple is formed by the lift-off method, the ion milling method, and the reactive-ion-etching method. Although not illustrated, an upper gap, an upper shield, and the Records Department is further formed on it.

305] Moreover, with the form 5 of operation having shown, similarly, by making it smaller than HMD more greatly than LD, HD does not have the reproducing head suitable for the \*\* width of recording track, and can be manufactured with the sufficient yield. Moreover, by setting sum total thickness of a magnetization fixing layer, a nonmagnetic interlayer, and a magnetization free layer to 14nm or less, the resistance of the spin bulb film 13 can be raised, a production output can be heightened, and a high sensitivity magnetoresistance-effect head can be obtained.

306] \*\*\*\* 6.

Form : the thermal resistance and the mirror plane of the 7th operation)

307] First, before introducing the example of this operation form, the technical problem recognized in process in which this invention person results in this operation form is explained.

308] The technical problem which this invention person has recognized can be divided roughly into below in putting highly efficient spin bulb film (it being hereafter described as SV film) in practical use.

309] (1) Thermal resistance is bad (receiving especially initial process annealing).

310] (2) When aiming at much more improvement in reproduction sensitivity, MR rate of change runs short.

311] (3) When a magnetosensitive layer is constituted from a CoFe alloy-layer monolayer from which comparatively high MR rate of change is obtained, magnetostriction control cannot be performed, and good soft magnetic characteristics are not obtained.

312] The technical problem of these SV films is explained in full detail below.

313] (1) As general composition of the magnetosensitive layer of heat-resistant SV film, NiFe (several nm)/Co (about 1nm) and NiFe(several nm)/CoFe (about 1nm) are known. As SV membrane structure (a) using such a magnetosensitive layer Ta(5nm)/NiFe(10nm)/Co(1nm)/Cu(3nm)/CoFe(2nm)/IrMn (7nm) / Ta (5nm)

(b) Ta(5nm)/Cu(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

\*\*\* is mentioned.

314] By SV film which was described above, thing MR degradation will arise about 20% or more to MR value at the time of as-depo at a relative ratio by about [ 250 degree-Cx4H ] process annealing. For example, by SV film of (a), 4.4% of MR rate of change at the time of as-depo will deteriorate 20% or more by the relative ratio to the time of 4.7% and as-depo after annealing which is 250 degree-Cx3H. This annealing process is a process it is [ a process ] indispensable on head production. After annealing of 250 degree-Cx3H, about 20% of degradation produces MR rate of change at the time of as-depo as compared with 6.5% and the time of as-depo to SV film of (b) which does not use \* and NiFe as a magnetosensitive layer being 8.1%. For the moment, the technique improved without sacrificing magnetic properties for degradation of such MR rate of change, i.e., a heat-resistant remedy, is not found out.

315] Although a SV film which has higher MR rate of change is desired in the magnetic head towards densification, MR rate of change obtained at the time of as-depo is remarkably reduced in a thermal process with the indispensable reduction process top of a head by SV film obtained by present as mentioned above. This is the problem which must surely be solved when developing the MR head which was with 10 or more Gdpsis and was made to correspond to recording density [ like ].

316] (2) In order to attain the improvement quantity MR rate of change of MR rate of change by use of a reflection effect With how MR rate of change obtained at the time of as-depo shown by (1) is maintained after a thermal process

is also important how the absolute value of MR rate of change is raised or how even if MR rate of change of full potential is not obtained in the time of as-depo, a film with which MR rate of change good after a thermal process is obtained is realized.

[317] the range with the GMR effect shorter than an electronic mean free path -- if -- since the number of times which receives spin dependence dispersion increases so that there are many number of layers of the cascade screen of a magnetic layer/non-magnetic layer, MR rate of change becomes large. However, like SV membrane structure, since there are only units, such as a magnetization fixing layer / nonmagnetic interlayer / magnetosensitive layer, in the structure of the GMR film actually used with a head, generally it is short thickness from the mean free path, and is sing in MR rate of change.

[318] In order to improve this, as structure which increased the number of layers, a magnetization fixing layer is made vertical two-layer, and the dual spin bulb film (or SHIMETORI-spin bulb film (it is hereafter described as a D-SV film)) which has arranged the magnetosensitive layer in the meantime is known. Although this is also one cure, by the time it solves all practical problems, it will not have resulted at a present stage. For example, it is with the D-SV film from which the ground for a magnetosensitive layer serves as a nonmagnetic interlayer, the soft magnetic characteristics  $H_k$ , for example, the anti-magnetic field, of a magnetosensitive layer. It is difficult to satisfy all the magnetostrictions  $\lambda$  etc. Furthermore, although the one where the blocking temperature of the two-layer antiferromagnetism film which fixes magnetization two-layer [ these ] is more nearly equal is desirable when the magnetization fixing layer of two upper and lower sides is used, it is difficult to make equal the property of the antiferromagnetism film located in the bottom in fact, and the antiferromagnetism film located in an upper layer side through a nonmagnetic interlayer or a magnetosensitive layer. Therefore, although the D-SV film from the point of MR rate of change is desirable composition, many technical problems are included from a viewpoint of practicality.

[319] Then, it is a mirror plane as one means by which the antiferromagnetism film put in practical use now raises the property of SV film of the general structure of one layer. This arranges a reflective film on one side or the vertical both sides of a basic unit of a magnetic layer / nonmagnetic interlayer / magnetic layer, reflects an electron elastically, and lengthens the mean free path within the basic unit of a GMR film. [ of a GMR film ]

[320] Conventionally, since only the distance of the mean free path which it should originally have since inelasticity-dispersion was received was not able to move an electron and spin dependence dispersion more than the thickness of the basic unit of a GMR film was not able to be received, it was losing on the vertical layer of the basic unit of a GMR film in MR rate of change. If it uses the reflective film of vertical both ideal layers, seemingly, a GMR basic unit becomes an infinite artificial grid and infinite equivalence, and since only the part of the mean free path which originally moves can receive spin dependence dispersion now, MR rate of change will improve. Thus, the reflective film on the outside of the magnetic layer located in a nonmagnetic interlayer's upper and lower sides itself demonstrates an effect enough by the reflection which is not dependent on spin even if it is not a reflective film depending on spin.

[321] The above-mentioned effect demonstrates an effect also not only in general SV membrane structure but in a D-SV film. However, there are many number of layers from the first, and there is no effect of a reflective film in the artificial grid of the infinite number of layers which has received spin dependence dispersion by the original mean free path. Thus, SV membrane structure with few number of layers from the first has a larger effect.

[322] A mirror plane which was conventionally mentioned above

[323] (c) Si substrate / NiO(50nm)/Co(2.5nm)/Cu(1.8nm)/Co(4nm)/Cu(1.8nm)/Co(2.5nm)/NiO (50nm)

(d) Si substrate / NiO(50nm)/Co(2.5nm)/Cu(2nm)/Co(3nm)/Au (0.4nm)

Ref.J.R.Jody et.al., IEEE Mag.33 No.5.3580 (1997)) (e) MgO substrate / Pt(10nm)/Cu(5nm)/NiFe(5nm)/Cu (2.8nm)/Co(5nm)/Cu (1.2nm) / Ag (3nm)

Japan Institute of Metals 1997 spring convention [ besides Ref. river part Yasuhiro ] lecture outline p142)

(f) Si substrate / Si<sub>3</sub>N<sub>4</sub> / (200nm) Bi<sub>2</sub>O<sub>3</sub> / (20nm) Au(4nm)/NiFe(4nm)/Cu(3.5nm)/CoFe (4nm)

Ref.D.Wang et al.,IEEE Mag 32 No.5.4278(1996))

In addition, the portion which attached the underline among SV membrane structures mentioned above is a portion considered to be a specular reflection film.

[324] By SV film of the above (c), the specular reflection film with which vertical both layers consist of an oxide is used. The way which used the insulating oxide with a potential barrier higher than a metal in order to cause reflection of an electronic wave, even if it thinks simply is a mirror plane. Furthermore, since a NiO film is also an antiferromagnetism film while it is an oxide reflective film, it has also played the role which fixes magnetization of the magnetic layer which is in contact with NiO. Although the above-mentioned composition is a D-SV film, antiferromagnetism films, such as a normal SV film and a reversal SV film, are considered that the specular reflection of one side is acquired even for the structure of one layer. However, there are some faults by such film and it is not

actical at a present stage.

325] First, the switched connection force is weak and practicality of NiO is low. In a weak coupling magnetic field, the magnetization direction of a magnetization fixing layer becomes unstable by the disclosure magnetic field from a cord medium, and there is a possibility of changing an output. Furthermore, in using an oxide layer for the upper layer, make it NiO -- moreover, carry out using another oxide as a cap layer -- contact resistance with a lead electrode will become large. Since it becomes easy to cause ESD (electro static discharge : electrostatic discharge), increase of contact resistance is not desirable. Furthermore, when CoFe is used for a magnetosensitive layer, if fcc (111) orientation of the CoFe is not carried out, it turns out that a good soft magnetism is unrealizable. When a magnetosensitive layer is located in a lower layer, since the buffer layer of fcc (111) orientation will be lost for CoFe, being compatible [ with soft magnetic characteristics ] of using an oxide layer as a ground of a magnetosensitive layer becomes difficult.

326] Moreover, by SV film of (d), the antiferromagnetism [ a reflective film-cum- ] film of NiO is used for a ground layer, and Au layer on the front face of a film serves as a reflective film further. Moreover, similarly, SV film of (e) is so a reflective film, uses the potential difference on Ag film and the front face of a film, and Ag film on the front face of a film is a mirror plane. Although the reason the effect was acquired by noble-metals film like Au or Ag as a reflective film on the front face of a film is not clear, since the surface diffusion on the front face of a film tends to happen [ noble metals ] to the reference of (d) from transition metals as one reason, flat nature becomes high and it is indicated by the noble-metals film front face that it is for being easy to pull out a reflection effect.

327] It is advantageous at the point which can do small contact resistance with the lead electrode which was a trouble at the time of an oxide reflective film by the reflective film which used for the film front face a metal membrane which is as described above. However, the mirror plane on the front face of a film of a noble-metals film like Au or Ag. That is, it is rare that the front face of SV film is exposed as it is in actual MR element and an actual MR head, and, usually the laminating of a certain film is carried out on SV film.

328] For example, in a shielded type MR head, the laminating of the up magnetic-gap film which consists of an alumina etc. is carried out on SV film. It is a mirror plane as indicated by the reference of (d). If the laminating of another film is carried out on the film with which it used the reflection effect on the front face of a film from the first, naturally a reflection effect will change. Thus, the membrane structure to which MR property is changed with the film by which a laminating is carried out on SV film has a problem in respect of practical use.

329] If the laminating of the Ta film usually well used for Au film front face of SV film of (d) as a protective coat is actually carried out, it is reported that a reflection effect is lost. Thus, the mirror plane on the front face of a film

330] Although SV film of (f) uses Au film as a specular reflection film like (d), this is a mirror plane in not the reflection effect on the front face of a film but the film interface of metal membranes. The interface with NiFe by which elaborates a ground by SV film of (f), and makes Au film front face a flat as much as possible, and a laminating is carried out on it here in order that it may be known that it will be easy to carry out island growth and it may suppress it, if Au film forms membranes directly on a substrate without a suitable ground layer is made sharp.

331] However, the ground layer of (f) cannot be called practical technique. That is, it is Bi<sub>2</sub>O<sub>3</sub> about Au film. It is seen that a good reflection effect can be pulled out if membranes are formed on a film and annealing is performed at 50 degrees C. the Bi<sub>2</sub>O<sub>3</sub> film with a thickness of 20nm is used as a ground (Ref.C.R.Tellier and A.J.Tosser.Size Effects in Thin Films, Chapter I.Elsevier, and 1982 --) L. I.Maissel et al., Handbook of Thin Film Technology.McGRAW-Hill Publishing Company, 1983.

332] Furthermore, Si<sub>2</sub>O<sub>3</sub> It is Si<sub>3</sub>N<sub>4</sub> with a thickness of 200nm as a membranous ground. The film is used. That is, the ground film with a total thickness of no less than 220nm was used upwards as a ground of Au film, and it has passed through the annealing process in the elevated temperature of 350 degrees C. If the thickness of 220nm will consider a bird clapper to a narrow gap increasingly in connection with densification from now on, not only becoming being remarkable and disadvantageous but practicality is very low. Furthermore, heat treatment in the elevated temperature of 350 degrees C will cause interface diffusion by the magnetic layer / nonmagnetic interlayer interface which causes basic spin dependence dispersion for a GMR film, and MR rate of change will deteriorate remarkably. This temperature is temperature from which interface diffusion also produces SV film using the Co(CoFe)/Cu/Co(CoFe) cascade screen which was [ even if ] excellent in thermal resistance.

333] (3) When using the magnetostriction control CoFe layer of CoFe as a magnetosensitive layer, fcc (111) orientation of the CoFe layer is carried out by applying the ground layer which carried out fcc (111) orientation, and it is found out that it is possible to raise soft magnetic characteristics by this. Here, Cu layer and Au layer are used as a ground layer which carried out fcc (111) orientation. However, about the magnetostriction which is another important element of soft magnetic characteristics, it was not controlled at all, and thermal resistance also found out that it was greatly dependent on a ground layer this time. For example, a membrane structure as shown below as a SV film based

1 the above-mentioned official report is mentioned.

0334] (g) Ta(5nm)/Cu(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

0335] (h) Ta(5nm)/Au(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

0336] In the above-mentioned film of (g), fcc (111) orientation of the Cu film is carried out. Although fcc (111) orientation of the CoFe layer on this fcc(111) Cu film is carried out and a soft magnetism can be realized (i) It cannot be said that the absolute value of  $\lambda$  is large etc. has not necessarily satisfied practicality fully with the (ii) magnetostriction  $-14 \times 10^{-7}$ . [ with bad (after as-depo: 8.1%  $\rightarrow$  250 degree-Cx4H : 6.5% (MR rate of change deteriorates 30% in a relative ratio)) thermal resistance ] Although there is no clear indicator of Magnetostriction  $\lambda$ , as one criteria,  $-10 \times 10^{-7}$  to  $+10 \times 10^{-7}$  to about seven can say that it is desirable.

0337] Furthermore, when it replaces with Cu as a fcc material and Au is used (film of (h)) (i) It cannot be said that practicality is not necessarily satisfied fully like the case where Cu film -- an absolute value is large -- is used with the (ii) magnetostriction  $\lambda + 33 \times 10^{-7}$ . [ with bad (after as-depo: 8.4%  $\rightarrow$  250 degree-Cx4H : 6.5% (MR rate of change deteriorates 23% in a relative ratio)) thermal resistance ]

0338] The  $\theta$ - $2\theta$  scan measured and estimated the XRD pattern of the spin bulb film of the above (g) and (h). Since it was almost same d spacing value by three layer of CoFe/Cu/CoFe and had become one peak, the peak value was taken. At this time, d-(111) spacing value of the fcc orientation of three layer of CoFe/Cu/CoFe on Cu was 0.054nm, and d-(111) spacing value of the fcc orientation of three layer of CoFe/Cu/CoFe on Au was 2.086nm. Since the suitable small magnetostriction value was taken when making it the mean value of d-(111) spacing value on these Cu ] and Au so that it might mention later, it turns out that too small d-(111) spacing value on Cu and too large d-(111) spacing value on Au are not desirable.

0339] Thus, when using the magnetosensitive layer which consists of a CoFe layer, even if it formed membranes on the ground layer which only carried out fcc (111) orientation, the point of a magnetostriction showed that it was inadequate. In addition, CoFe is formed on nickel<sub>80</sub>Fe<sub>20</sub> which is near the zero magnetostriction and carried out fcc (111) orientation as one of the technique to which a magnetostriction is satisfied, and although the structure (the above-mentioned composition of (a)) which makes a magnetostriction zero as the whole magnetosensitive layer by about 0  $\mu$ Fe in magnetostriction is mentioned, this composition has the problem [ mentioned / above ] that thermal-process degradation of MR property is large.

0340] As mentioned above, the conventional spin bulb film is wanted to raise the thermal resistance of a spin bulb film, since decline in MR rate of change by the thermal process is large.

0341] Moreover, it is a mirror plane as an improvement measure of MR rate of change of a spin bulb film. In order for the reflective films in the conventional spin bulb film to be insulators, such as an oxide, and to use the reflection effect on the front face of a film, For example, it is a mirror plane, when increase of contact resistance with a lead electrode causes ESD or a protective coat etc. is formed on a spin bulb film. Furthermore, although using a reflection effect by the interface was also examined, as for practicality, it was very low that there was the need of preparing a ground layer near for the reason etc. It is a mirror plane, after taking into consideration the practicality as an element or the magnetic head, since it was such.

0342] Furthermore, controlling small the magnetostriction of Co system magnetic layer which consists of a CoFe alloy etc., when raising the soft magnetic characteristics of a spin bulb film is called for.

0343] Especially, it is a mirror plane.

0344] The magnetoresistance-effect element which has the spin bulb film which was invented in order that this operation form might cope with such a technical problem, and suppressed the fall of MR property by the thermal process, Moreover, it aims at offering the magnetoresistance-effect element which has the spin bulb film which raised MR rate of change according to the specular reflection effect after taking practicality into consideration, the spin bulb film which realized the low magnetostriction, and the spin bulb film which suppressed these thermal-process degradation further. Furthermore, it aims at offering the magnetic head and the magnetic recording medium which raised record reproducing characteristics and practicality by using such a magnetoresistance-effect element.

0345] The gestalt of the operation for solving hereafter the technical problem mentioned above is explained with reference to a drawing.

0346] Drawing 32 is the cross section showing the important section structure of 1 operation gestalt of the magnetoresistance-effect element (MR element) of this invention. In this drawing, 1 is the 1st magnetic layer and 2 is the 2nd magnetic layer. The laminating of these [ 1st ] and the 2nd magnetic layer 1 and 2 is carried out through the nonmagnetic interlayer 3. Antiferromagnetism combination is not carried out between the 1st and the 2nd magnetic layer 1, and 2, but it constitutes the magnetic uncombined type multilayer.

0347] The 1st and 2nd magnetic layers 1 and 2 are constituted by the ferromagnetic containing Co like for example, Co simple substance or Co alloy. Magnetic layers 1 and 2 may consist of NiFe alloys etc. It is desirable to use Co alloy

th which especially a bulk effect and the interface effect can both be enlarged, and big MR variation is obtained among these.

346] The alloy which added one sort or two sorts or more of elements chosen as Co from Fe, nickel, Au, Ag, Cu, Pd, Ir, Rh, Ru, Os, Hf, etc. as a Co alloy which constitutes magnetic layers 1 and 2 is used. As for the amount of alloying elements, it is desirable to consider as five to 50 atom %, and it is desirable to consider as the range of further - 20 atom %. This is because there is a possibility that the interface effect may decrease when a bulk effect will not increase if there are too few amounts of alloying elements, but there are too many amounts of alloying elements inversely. When obtaining big MR variation, as for an alloying element, it is desirable to use especially Fe.

347] The 1st lower magnetic layer 1 is formed among the 1st and 2nd magnetic layers 1 and 2 on the improvement layer 4 in the magnetoresistance effect (improvement layer in MR). The improvement layer 4 in MR is formed on the non-magnetic layer (it is hereafter described as a nonmagnetic ground layer) 5 which has a ground function. This nonmagnetic ground layer 5 is a layer containing at least one sort of elements chosen from Ta, Ti, Zr, W, Cr, Nb, Mo, f, and aluminum, and consists of compounds, such as these simple substance metals and alloys or an oxide, and a tride. When oxides, such as Ta, are used for the nonmagnetic ground layer 5, the electron which was not able to be reflected in the improvement layer 4 in MR can be reflected by nonmagnetic ground layer 5 / improvement layer in MR 4 interface so that it may explain in full detail behind.

348] The 1st magnetic layer 1 is a magnetosensitive layer from which the magnetization direction changes with external magnetic fields. On the other hand, on the 2nd magnetic layer 2, the antiferromagnetism layer 6 which consists of IrMn, NiMn, PtMn, FeMn, RuRhMn, PdPtMn, MiO, etc. is formed. The bias magnetic field was given to the 2nd magnetic layer 2 from the antiferromagnetism layer 6, and the magnetization has fixed. That is, the 2nd magnetic layer is a magnetization fixing layer.

349] Although not illustrated in drawing 32, besides the method of touching an antiferromagnetism film directly as mentioned above as the fixing method of the 2nd magnetic layer, making carry out, and fixing the magnetization direction You may use the so-called synthetic anti ferro structure of carrying out the laminating of the 3rd magnetic layer through layers, such as Ru and Cr, on the 2nd magnetic layer, carrying out antiferromagnetism combination of the 2nd magnetic layer and 3rd magnetic layer in RKKY, and carrying out antiferromagnetism combination of the 3rd magnetic layer. By using synthetic anti ferro structure, a bias point also becomes stable and the stability under the elevated temperature of a pin property also increases. Specifically, CoFe/Ru/CoFe, Co/Ru/Co, CoFe/Cr/CoFe, o/Cr/Co, etc. are mentioned as composition from the 2nd magnetic layer to the 3rd magnetic layer. The antiferromagnetism film at this time is the same as that of a group of an above-mentioned antiferromagnetism film.

350] The alloy which makes a principal component Cu, Au, Ag and these alloys or the paramagnetic alloy containing these and a magnetic element, Pd and Pt, and these as a component of the 1st and 2nd magnetic layers 1 and the non-magnetic layer 3 arranged among two is illustrated.

351] The protective layer 7 is formed on the antiferromagnetism layer 6, and this protective layer 7 is constituted by the same metal or same alloy as the nonmagnetic ground layer 5. The spin bulb film 8 of this operation form is constituted by these each class. The electrode (not shown) of the couple which supplies sense current is connected to the spin bulb film 8, and a spin bulb GMR element is constituted by these. The spin bulb GMR element may have the bias magnetic field impression film which consists of a hard magnetic film which impresses a bias magnetic field to the magnetosensitive layer 1, or an antiferromagnetism film. In this case, as for a bias magnetic field, it is desirable to impress in the direction which carries out an abbreviation rectangular cross to the magnetization direction of the magnetization fixing layer 2. In addition, nine in drawing is a substrate.

352] The improvement layer 4 in MR which the improvement layer 4 in MR is the characteristic portion of this invention, and is shown in drawing 32 is constituted by the cascade screen of 1st metal membrane 4a and 2nd metal membrane 4b among each class which constitutes the spin bulb film 8 mentioned above. The metal membrane containing at least one sort of elements chosen from Cu, Au, Ag, Pt, Rh, aluminum, Ti, Zr, Hf, Pd, and Ir is applicable to the metal membranes 4a and 4b which function as a ground of the spin bulb film 8.

353] The element which mainly constitutes 1st metal membrane 4a which touches the 1st magnetic layer (magnetosensitive layer) 1 among the metal membranes of these plurality has a relation of the element which mainly constitutes the magnetosensitive layer 1, and not dissolving. It may be desirable to have a relation of the element with which the element which mainly constitutes it mainly constitutes the magnetosensitive layer 1 also about the 2nd metal membrane 4b, and not dissolving, and each element which mainly constitutes especially these [ 1st ] and the 2nd metal membrane 4a and 4b may have the relation of dissolution mutually. Furthermore, it is desirable to arrange 1st metal membrane 4a to which an electron wavelength becomes the side which touches the magnetosensitive layer 1 from a short metal, and to arrange 2nd metal membrane 4b with a long (1st metal membrane 1a) electron wavelength on the outside.

354] Here, the relation of not dissolving in this invention is stated. In this invention, the state of having a non-dissolving relation the element A, and two kinds of elements of the element B In the phase diagrams (for example, binary Alloy Phase Diagram, 2nd Edition, ASM International.1990, etc.) of two elements in the low-temperature region about a room temperature The combination of the element both the amount of atomic %s in which B can dissolve when A is used as a base material, and whose amount of atomic %s in which A can dissolve when it considers B base material are 10% or less shall be shown.

355] As an example, the time of a magnetic layer (for example, magnetosensitive layer 1) being Co or Co alloy and the case where a magnetic layer is nickel alloy are explained. Since it is desirable for ground films to be a fcc metal and a hcp metal in order to make a magnetic layer into fcc orientation, as a concrete composition element of the improvement layer in MR which touches a magnetic layer, aluminum, Ti, Cu, Zr, Ru, Rh, Pd, Ag, Hf, Ir, Pt, Au, etc. are mentioned. The element with which it is satisfied of the above-mentioned conditions of Co and un-dissolving, among these elements turns into three elements of Cu, Ag, and Au. Moreover, nickel and the element with which are satisfied of the above-mentioned conditions of un-dissolving turn into three elements of Ru, Ag, and Au. However, though Cu had the relation of dissolution when only the phase diagram was referred to when nickel alloy was used as magnetic layer, when it used as an improvement layer in MR as a result of this invention person's experiment, it became clear that it can say un-dissolving. That is, nickel alloy and Cu are judged un-dissolving based on the following experimental results.

356] Although the improvement layer in MR acts as a nonmagnetic quantity conductive layer in the 1st operation form mentioned above when \*\*\*\*\* and a free layer are thin, if atomic diffusion arises in the interface of a nonmagnetic quantity conductive layer and a free layer and it becomes a diffusive interface, the permeability of the electron which goes to a nonmagnetic quantity conductive layer from a free layer will be reduced. That is, in order that the magnetization direction of a pin layer and a free layer may receive inelastic scattering in a diffusive interface also the parallel state mutually, the mean free path of rise spin does not become long. That is, decline in MR rate of change will be caused. an ultra-thin free layer and the nonmagnetic quantity conductive layer of this phenomenon are dissolution -- by the way, it is generated, and it will become more remarkable if heat treatment of a process etc. is performed That is, MR rate of change falls with heat treatment. When the experiment which attached Cu to thin nickel alloy layer when the method of checking such a phenomenon was taken was conducted, decline in MR rate of change was not seen.

357] From the above result, nickel alloy and Cu are judged un-dissolving. Therefore, as nickel alloy and an element with which are satisfied of a non-dissolving relation, by this invention, Cu can be added to the combination of the element obtained from a phase diagram, and it can be defined as Ru, Ag, Au, and Cu. It is a mirror plane, without using the composition \*\*\*\*\* of the interface of a magnetic layer and the improvement layer in MR by heat treatment etc. by arranging the element of such not dissolving, in contact with a magnetic layer.

358] Here, although premised on carrying out fcc orientation of the magnetic layer, you may use these improvement layers in MR to the magnetic layer which, of course, has non-orientation and microcrystal structure. Specifically, the amorphous magnetic layer by which Ti, Zr, Nb, Hf, Mo, Ta, etc. were added, or a magnetic layer with microcrystal structure is mentioned to CoFeB, CoZrNb, and Cr as a magnetic layer.

359] Furthermore, in order to make control and the film fine structure of d-spacing into more exact structure to a part of improvement layer in MR constituted with the above-mentioned element, another element in making it a cascade screen with another metal membrane and the alloyed layer are improvement layers in MR by this invention. As an element which constitutes this film by which a laminating is carried out, a fcc metal and a hcp metal are desirable and aluminum, Ti, Cu, Zr, Ru, Rh, Pd, Ag, Hf, Ir, Pt, Au, etc. are mentioned.

360] When applying a cascade screen to the improvement layer in MR, the metal which has the metal membrane of the side which is in contact with the magnetic layer, and the relation of dissolution as a desirable example of the metal membrane of the side which is not in contact with a magnetic layer is mentioned. The combination of the element with which it is a low-temperature region about a room temperature, and both the amount of atomic %s in which B can dissolve when A is used as a base material, and the amount of atomic %s in which A can dissolve when it considers as B base material exceed 10% like the case of not dissolving [ which was described above as the state of having the relation of dissolution of the element A, and two kinds of elements of the element B here ] shall be shown.

361] The desirable example at the time of applying a cascade screen to the improvement layer 4 in MR is shown. When a magnetic layer 1 consists of Cu(s) which fill the conditions of it and un-dissolving with Co or Co alloy, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from aluminum, Au, Pt, Rh, Pd, and Ir which fulfill the conditions of the above-mentioned dissolution. [ a / metal membrane ] When metal membrane 4a is constituted from Ag, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from Pt, Pd, and Au. When metal membrane 4a is constituted from

1, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from Pt, Pd, Ag, and aluminum. When a magnetic layer 1 consists of Ru which fills the conditions of it and non-dissolving with nickel alloy, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from Rh, Ir, and Pt which fulfill the conditions of the above-mentioned dissolution. [a / metal membrane 4] When using Ag and Au, it is as having described above.

362] It is desirable for two elements which constitute the improvement layer 4 in MR among combination which was mentioned above to dissolve mutually 10% or more, for example, Au-Cu, Ag-Pt, Au-Pd, Pt-Cu, Au-Ag, etc. are mentioned. In addition, it is also possible for the combination of metal membrane 4a and metal membrane 4b not to have to fill the relation of the dissolution described above not necessarily, and to apply the combination of Cu-Ru and Au-Ag etc. Not only the two-layer cascade screen of 1st metal membrane 4a and 2nd metal membrane 4b but the improvement layer 4 in MR which consists of a cascade screen can be constituted from a cascade screen of three or more layers.

363] The improvement layer 4 in MR can also constitute the improvement layer 4 in MR from alloy-layer 4c of the element which mainly constitutes the magnetosensitive layer 1, and the element which has a non-dissolving relation, as shown not only in the cascade screen of 1st metal membrane 4a and 2nd metal membrane 4b but in drawing 33. The same view as the above-mentioned cascade screen is applicable to alloy-layer 4c in this case. That is, when a magnetic layer 1 consists of Co or a Co alloy, alloy-layer 4c contains at least one sort chosen from three elements of Cu, Ag, and Au as a main composition element. Moreover, when a magnetic layer 1 consists of a nickel alloy, alloy-layer 4c contains at least one sort chosen from four elements of Ru, Ag, Au, and Cu as a main composition element.

364] Alloy-layer 4c contains at least one sort of elements in addition to the above-mentioned main composition element. The main composition element and the element of dissolution are used for elements other than this main composition element so that it may not become 2 phase separation films. For example, when Cu is used for the main composition element of alloy-layer 4c, the alloy of noble-metals systems, such as Cu-Au, Cu-Pt, Cu-Rh, Cu-Pd, and Cu-Ir, is used. When Ag is used for the main composition element of alloy-layer 4c, the alloy of noble-metals systems, such as Ag-Pt, Ag-Pd, and Ag-Au, is used. When Au is used for the main composition element of alloy-layer 4c, the alloy of noble-metals systems, such as Au-Pt, Au-Pd, Au-Ag, and Au-aluminum, is used.

365] Among alloys which were mentioned above, as for alloy-layer 4c as an improvement layer 4 in MR, it is desirable for two elements to dissolve mutually 10% or more, for example, Au-Cu, Ag-Pt, Au-Pd, Au-Ag, etc. are mentioned. Thus, it is also possible to constitute the improvement layer 4 in MR from a cascade screen of metal membrane 4a and alloy-layer 4c, as various forms can be applied to the improvement layer 4 in MR, for example, it is shown in drawing 34.

366] When using Co system magnetic material for the magnetosensitive layer 1, as for the improvement layer 4 in MR as a ground of the magnetosensitive layer 1, it is desirable to use the metallic material which has the same fcc crystal structure as Co system magnetic material, and the metallic material of the hcp structure to which it is easy to carry out fcc orientation of the film on it. Cu, Au, Ag, Pt, Rh, Pd, aluminum, Ti, Zr, Hf(s), Ir(s), etc. which were mentioned above also from such a point, and those alloys are suitable as a component of the improvement layer 4 in MR. Furthermore, by using the improvement layer 4 in MR which consists of the cascade screen or alloy layer of such metal, the magnetostriction of the magnetosensitive layer 1 which consists of Co system magnetic materials, such as CoFe alloy, can be reduced so that it may explain in full detail behind.

367] In order to give the function as a ground layer, as for the thickness of the improvement layer 4 in MR, it is desirable to be referred to as 2nm or more. However, if it is made not much thick, in order that MR rate of change may decrease by increase of shunt diverging, it is desirable still more desirable to be referred to as 10nm or less, and the thickness of the improvement layer 4 in MR is 5nm or less.

368] The work which raises the thermal resistance of the spin bulb film 8 as for the improvement layer 4 in MR which was mentioned above, It works. when the work as a specular reflection film (interface reflective film) of the spin bulb film 8 and a free layer are thin, MR rate of change is maintained to a high value -- It works, and has the work which reduces the magnetostriction of the magnetosensitive layer 1 which consists of a Co system magnetic material and which controls the crystal fine structure of the spin bulb film 8, and the MR property of the spin bulb film 8 is raised based on these. Below, work of the improvement layer 4 in MR is explained in full detail.

369] First, thermal-process degradation of a spin bulb film is described. The mirror plane of the side which is not in contact with the nonmagnetic interlayer 3 of magnetic layers 1 and 2 as a cause of degradation of MR property by process annealing The situation is shown in drawing 35. In addition, it sets to drawing 35 and is IFS. The interface and FM by which spin dependence dispersion is carried out The interface by which not spin dependence dispersion but mirror-plane distraction is carried out is shown. Drawing 35 (a) and (b) show the ideal state (it corresponds at the time of as-depo), and drawing 35 (c) shows the state after process annealing typically.

370] In the three-layer laminated structure of magnetosensitive layer 1 / nonmagnetic interlayer 2 / magnetization  
 king layer 3 which serves as a basic unit of the spin bulb GMR as shown in drawing 35 (a) and (b) As shown in  
 awing 35 (c) (even if the interface is an interface with a metal membrane), what the mirror-plane scattering effect in  
 e both sides had produced at the time of as-depo Interface diffusion arises by system which dissolves mutually easily  
 / process annealing, and it becomes a dispersion-interface, and is a mirror plane.

371] The mirror plane in a metal membrane interface For example, in an as-depo state with comparatively little  
 ixing, it is a mirror plane also at a NiFe/CoFe interface.

372] With the spin bulb film which used concretely the magnetosensitive layer which consists of a NiFe/CoFe  
 iscade screen, it is the mirror plane of a NiFe/CoFe interface. It is also considered that change of MR rate of change  
 / change of the specular reflection factor in the NiFe/CoFe interface by annealing took place as this cause.

373]

---

ince it became timeout time, translation result display processing is stopped.

## NOTICES \*

Japan Patent Office is not responsible for any damages caused by the use of this translation.

This document has been translated by computer. So the translation may not reflect the original precisely.

\*\*\*\* shows the word which can not be translated.

In the drawings, any words are not translated.

## ETAILED DESCRIPTION

## Detailed Description of the Invention]

[001]

The technical field to which invention belongs] this invention relates to the magnetoresistance-effect element using a spin bulb film with which this invention has high sensitivity and high-reliability in a detail, the magnetic head, a magnetic-head assembly, and a magnetic recording medium more about a magnetoresistance-effect element, the magnetic head, a magnetic-head assembly, and a magnetic recording medium.

[002]

Description of the Prior Art] The expectation for the magnetic head (MR head) using the magnetoresistance effect (MR) which can take out a big output from small and large capacity-ization of a magnetic-recording medium being advanced in recent years is growing. As a MR film used as the basic component of such an MR head It has the magnetic multilayer of the sandwich structure of a magnetic layer / non-magnetic layer / magnetic layer especially. one magnetic layer -- exchange bias -- doing -- magnetization -- fixing (a "magnetization fixing layer" --) Flux reversal of the magnetic layer of another side called a "fixing layer" or a "pin layer" is carried out by the external magnetic field called a "magnetosensitive layer" or a "free layer"). The spin bulb film in which the huge magnetoresistance effect (GMR) is shown by relative angle change of the magnetization direction of these two magnetic layers attracts attention.

[003] As other MR films, an anisotropy magnetoresistance-effect film (AMR film), an artificial grid film, etc. which consist of a NiFe alloy etc. are known. MR rate of change of a spin bulb film is 4% or more, although it is small compared with an artificial grid film, and it is fully large as compared with the AMR film. Furthermore, since a spin bulb film can saturate magnetization with a low magnetic field, it fits the MR head. It has a practically great hope for the MR head using such a spin bulb film. That is, in magnetic recording, such as a magnetic disk, the high sensitivity magnetic head which used the huge magnetoresistance effect (GMR), i.e., a GMR head, is indispensable to advance densification of recording density.

[004] The spin bulb film which consists of a magnetization free layer (free layer), a nonmagnetic interlayer, a magnetization fixing layer (pin layer), and an antiferromagnetism layer is used for an early GMR head as a GMR element. however -- if the thickness of a magnetization free layer is reduced in order to aim at improvement in sensitivity indispensable to narrow the width of recording track of record and to perform densification -- the disclosure magnetic field from a magnetization fixing layer -- the shift of the operating point -- bringing -- coming -- this shift amount -- the yield -- good -- a current magnetic field -- an amendment -- things become difficult

[005] The so-called laminating ferry fixing layer ("SyAF", "synthetic AF", or an "antiferromagnetism fixing layer" is called henceforth) which constituted the magnetization fixing layer from a two-layer ferromagnetic layer which carries out antiferromagnetism combination through a magnetic coupling layer on the other hand is proposed (JP,7-169026,A). Since the operating point is theoretically made to zero by the disclosure magnetic field in this antiferromagnetism fixing layer, reservation of the operating point is easy.

[006] Namely, if a ferromagnetic layer A and antiferromagnetism layer side is used as the ferromagnetic layer B, the nonmagnetic interlayer side of two ferromagnetic layers of this magnetization fixing layer The magnetic thickness, i.e., thickness, x saturation magnetization of the ferromagnetic layer A and the ferromagnetic layer B in equal SyAF Since the disclosure magnetic field of the ferromagnetic layer A and the ferromagnetic layer B is negated mutually, a disclosure magnetic field serves as zero substantially and a magnetization fixing layer stops inducing a magnetic field the stability of fixing magnetization is [ to / near / where the exchange bar chair of an antiferromagnetism layer disappears / the blocking temperature Tb ] good -- etc. -- it has a big merit

[007]

Problem(s) to be Solved by the Invention] However, there were various problems in these magnetoresistance-effect

ements by which the conventional proposal is made.

0008] First, in order to raise [ 1st ] sensitivity, when the free layer was thin-film-ized, there was a problem that the bias point design at the time of sense current energization became difficult.

0009] Since magnetization of SyAF becomes unstable in the temperature more than blocking temperature ( $T_b$ ) the head, if static discharge (ESD) current flows into a GMR element, a fixing layer will be momentarily heated by the temperature more than  $T_b$ , and the problem that fixing of magnetization will be confused arises. It is required to add the strong magnetic field (usually several more than kOe) exceeding the antiferromagnetism joint magnetic field through the magnetic coupling layer which raises temperature to more than  $T_b$  and moreover constitutes [ 3rd ] SyAF in order to fix magnetization. For this reason, when temperature is raised to more than  $T_b$  using the high antiferromagnetic substance of  $T_b$  for fixing of magnetization as an antiferromagnetism layer, there is a problem that to produce diffusion and antiferromagnetism combination falls between the ferromagnetic layers which adjoin the magnetic coupling layer of SyAF.

0010] In order to add the strong magnetic field (JP,9-16920,A 15 kOe(s)) exceeding the antiferromagnetism joint magnetic field which minds a magnetic coupling layer where a temperature rise is carried out to the 4th, a huge magnetization fixing thermal treatment equipment is needed.

0011] Although magnetization fixing will become easy in order to sympathize with an external magnetic field if it is made SyAF of unsymmetrical structure which changed the magnetic thickness of 2 ferromagnetism layers combined with the 5th in antiferromagnetism in the pin layer Before and after the heat-resistant requirements for the magnetic head needed in future high-density record, i.e., 200 degrees C, since the thermal resistance which came out on the other hand and was excellent in symmetrical SyAF will be lost, the problem that filling becomes difficult produces that magnetization fixing is stable. Moreover, since it will be accompanied by generating of a disclosure magnetic field, the problem that the cure of reservation of the operating point is also needed is also produced.

0012] There is also a trouble of 6th producing diverging of sense current and reducing the resistance rate of change as GMR element since a magnetic coupling layer and the ferromagnetic layer B are low resistance even if SyAF is a symmetrical system and it is an unsymmetrical system.

0013] furthermore, six troubles of having enumerated above -- (3) which runs short of MR rate of change when (1) thermal resistance aims at much more improvement in bad (receiving especially initial process annealing) (2) production sensitivity -- when a magnetosensitive layer was constituted from a CoFe alloy-layer monolayer from which comparatively big MR rate of change is obtained, magnetostriction control was not completed, but there were also problems -- good soft magnetic characteristics are not obtained -- [ in addition, ]

0014] this invention is made based on recognition of the various technical problems mentioned above. That is, the design of the bias point is easy for the purpose, and is to offer the magnetoresistance-effect element which has high sensitivity and high-reliability, the magnetic head, a magnetic-head assembly, and a magnetic recording medium.

0015]

Means for Solving the Problem] In order to attain the above-mentioned purpose, the magnetoresistance-effect element of this invention It has a nonmagnetic spacer layer, and the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were separated by the aforementioned non-magnetic-material spacer layer. the ferromagnetic layer of the above 1st It has the magnetization direction which accomplishes the angle to which it has received in the magnetization direction of the ferromagnetic layer of the above 2nd when an impression magnetic field is zero. the ferromagnetic layer of the above 2nd It is a magnetoresistance-effect element containing the ferromagnetic film of the couple mutually combined in antiferromagnetism, and the joint film which combines these in antiferromagnetism, separating the ferromagnetic film of the aforementioned couple. It is characterized by having the nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the film surface which a means to maintain the magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired, and the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an opposite side.

0016] A magnetoresistance-effect element with very high sensitivity is realizable with the above-mentioned composition, maintaining the good bias point.

0017] As a gestalt of desirable implementation of the above-mentioned composition, the aforementioned nonmagnetic quantity conductive layer becomes realizable [ the high MR rate of change by low  $H_{cu}$  realization and the spin-filter effect in an ultra-thin free layer ] by containing the element whose value of the specific resistance in the room temperature of a bulk state is 10 or less microohm-cm.

0018] moreover, it is characterized by the thickness which is the ferromagnetic layer of the above 1st being 0.5nm or more 4.5nm or less as composition suitable for realizing the effect of MR rate-of-change elevation by the object for high-density record, and the spin-filter effect by the nonmagnetic quantity conductive layer

- 019] Moreover, wave asymmetry  $(V1-V2)/(V1+V2)$  expressed with the absolute value V1 of the reproduction output in a right signal magnetic field and the absolute value V2 of the reproduction output in a negative signal magnetic field characterized by setting up the thickness of the aforementioned nonmagnetic quantity conductive layer, and the thickness of the ferromagnetic layer of the above 2nd so that it may become 0.1 or less 0.1 or more minus plus. In order to make wave asymmetry 0.1 or less 0.1 or more minus plus, it is not necessary to necessarily adopt SyAF and a pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs. 3. It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.
- 020] Moreover, it is t (HCL) (here) about the thickness of the aforementioned nonmagnetic quantity conductive layer. It  $t_m(s)$  (pin1). it converted in Cu layer of 10micro omegacm of specific resistance -- the magnetic thickness which converted the thickness of the ferromagnetic film of the aforementioned couple in the ferromagnetic layer of the above 2nd by the saturation magnetization of 1T, respectively When referred to as  $t_m$  (pin2) ( $t_m(\text{pin1}) >$  it is referred as  $t_m$  (pin2)), it is characterized by satisfying  $0.5 \text{ nm} \leq t_m(\text{pin1}) - t_m(\text{pin2}) + t(\text{HCL}) \leq 4 \text{ nm}$  and  $t(\text{HCL}) \geq 0.5 \text{ nm}$ . As long as it satisfies this relation, you may use  $t_m(\text{pin2}) = 0$ , i.e., the pin layer of a monolayer. By satisfying the above-mentioned relation, wave asymmetry becomes 0.1 or less plus by 0.1 or more minus, and high MR can be realized.
- 021] Moreover, the ferromagnetic layer of the above 1st is characterized by the magnetic thickness which is the product of the thickness and saturation magnetization being less than 5 nmTs.
- 022] Moreover, the copper which becomes advantageous [ the aforementioned nonmagnetic quantity conductive layer ] to having the conditions of low  $H_{in}$  realization (Cu), Gold (Au), silver (Ag), a ruthenium (Ru), iridium (Ir), It is characterized by being the metal membrane which contains at least a kind of metallic element chosen from the group which consists of a rhenium (Re), a rhodium (Rh), platinum (Pt), palladium (Pd), aluminum (aluminum), an osmium (Os), and nickel (nickel).
- 023] Moreover, the aforementioned nonmagnetic quantity conductive layer is characterized by being formed from the cascade screen which carried out the laminating of the film more than two-layer at least for low  $H_{in}$  and soft-magnetism property control.
- 024] When using this cascade screen, it is not necessary to necessarily adopt SyAF and the pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs. 3. It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.
- 025] Moreover, the film which touches the ferromagnetic layer of the above 1st among the aforementioned cascade screens is characterized by including copper (Cu) as a material which was excellent especially for high MR rate of change, low  $H_{cu}$  realization, and soft-magnetism realization.
- 026] Moreover, the film which does not touch the ferromagnetic layer of the above 1st among the aforementioned cascade screens is characterized by including at least a kind of element chosen from the group which consists of a ruthenium (Ru), a rhenium (Re), a rhodium (Rh), palladium (Pd), platinum (Pt), iridium (Ir), and an osmium (Os) as a material excellent in low  $H_{in}$ , low  $H_{cu}$ , and especially soft-magnetism control.
- 027] Moreover, thickness of the aforementioned nonmagnetic quantity conductive layer is characterized by 0.5nm or more being 5nm or less for realization of low  $H_{cu}$  and high MR rate of change.
- 028] Moreover, in order to realize low  $H_{in}$  and high MR rate of change, it is characterized by touching the aforementioned nonmagnetic quantity conductive layer in the ferromagnetic layer of the above 1st, and the field of an opposite side, and having the layer which contains at least a kind of element chosen from the group which consists of a tantalum (Ta), titanium (Ti), a zirconium (Zr), a tungsten (W), a hafnium (Hf), and molybdenum (Mo).
- 029] Moreover, the ferromagnetic layer of the above 1st is characterized by the bird clapper from the cascade screen of the alloy layer containing a ferronickel (NiFe), and the layer containing cobalt (Co) high MR rate of change and for soft-magnetism realization.
- 030] Moreover, the ferromagnetic layer of the above 1st is characterized by the bird clapper from the alloy layer containing cobalt iron (CoFe) high MR rate of change and for soft-magnetism realization.
- 031] Moreover, it is characterized by using an antiferromagnetic substance layer as a means to maintain the ferromagnetic layer of the above 2nd towards desired for magnetization fixing of the ferromagnetic layer of the above 2nd. Although it is desirable that it is SyAF as for the 2nd ferromagnetic layer, the ferromagnetic layer of a monolayer is sufficient as it. In the case of a monolayer, it is desirable for the magnetic thickness to be 3.6 or less nmTs in 0.5 or more nmTs.
- 032] Moreover, it is  $X_z\text{Mn}_{1-z}$  (X here) as a material of the aforementioned antiferromagnetic substance layer also after process heat treatment because of high MR rate-of-change realization. at least a kind of element chosen from the group which consists of iridium (Ir), a ruthenium (Ru), a rhodium (Rh), platinum (Pt), palladium (Pd), and a rhenium

le) -- carrying out -- the composition ratio  $z$  -- more than pentatomic % -- below 40 atom % -- it is -- it is characterized by using Also in this case, it is not necessary to necessarily adopt SyAF and the pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs. 3. It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.

[033] Moreover, in order to \*\* high MR rate of change, it is characterized by using  $XzMn_{1-z}$  (X considering as a kind of element chosen from the group which consists of platinum (Pt) and palladium (Pd) at least here, and the composition ratio  $z$  being below 65 atom % more than 40 atom %) as a material of the aforementioned antiferromagnetism layer. Also in this case, it is not necessary to necessarily adopt SyAF and the pin layer of a monolayer may be used. In this case, it is desirable to use the monolayer pin layer of the magnetic thickness of 0.5 or more nmTs at 3.6 or less nmTs.

It is difficult to be satisfied [ with 6 or more nmTs ] of the above-mentioned asymmetry, and is because MR rate of change becomes remarkably small in 0.5 or less nmTs.

[034] moreover, in order to realize realizing high MR rate of change, using more effectively the effect of the high MR rate of change by the nonmagnetic quantity conductive layer, and low  $H_{cu}$ , the aforementioned non-magnetic-material spacer layer consists of a metal layer containing copper (Cu), and the thickness makes it the feature to 1.5nm or more or 2.5nm or less

[035] Moreover, the ferromagnetic film of the aforementioned couple combined [ aforementioned ] in antiferromagnetism for the purpose of realizing high MR and raising an ESD-proof property and the thermal resistance of a pin fixing layer Those thickness is equal, the ferromagnetic film which touches the aforementioned nonmagnetic spacer side is thicker, and the difference of the magnetic thickness whose ferromagnetic film of the aforementioned couple is the product of each thickness and saturation MAG is characterized by 0 or more nmTs being 2 or less nmT.

[036] Moreover, the aforementioned joint film which combines the ferromagnetic film of the aforementioned couple antiferromagnetic substance consists of a ruthenium (Ru), and the thickness is characterized by 0.8nm or more being 2nm or less.

[037] On the other hand, the magnetoresistance-effect head of invention of the 1st of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, And it sets on the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film. It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes from the ferromagnetic layer B arranged at the aforementioned ferromagnetic layer which has been arranged at the aforementioned nonmagnetic interlayer side ] A, and antiferromagnetism layer side through a magnetic coupling layer. The aforementioned antiferromagnetism layer is a magnetoresistance-effect head to high orientation of the maximum \*\*\*\* is carried out, and it is characterized by the bird clapper so that the rocking curve half-value width of the maximum \*\*\*\* peak may become 8 degrees or less.

[038] The magnetoresistance-effect head of invention of the 2nd of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, And it sets on the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film. It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes from the ferromagnetic layer B arranged at the aforementioned ferromagnetic layer [ which has been arranged at the aforementioned nonmagnetic interlayer side ] A, and antiferromagnetism layer side through a magnetic coupling layer. or the aforementioned antiferromagnetism layer, the switched connection constant  $J$  with the aforementioned ferromagnetic layer [ in / 200 degrees C / thickness is 20nm or less and ] B is 0.02 erg/cm<sup>2</sup>. It is the magnetoresistance-effect head characterized by being above.

[039] The magnetoresistance-effect head of invention of the 3rd of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least to the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, And it sets on the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film. It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes

om the ferromagnetic layer B arranged at the aforementioned ferromagnetic layer [ which has been arranged at the aforementioned nonmagnetic interlayer side ] A, and antiferromagnetism layer side through a magnetic coupling layer. thickness is 20nm or less, and the aforementioned antiferromagnetism layer is  $Zx \text{ Mn } 1-x$  (it Ir(s) Z). It is the at least 1 ord chosen from Rh, Ru, Pt, Pd, Co, and nickel.  $0 < x < 0.4$  and  $Zx \text{ Mn } 1-x$  (Z is at least one sort chosen from Pt, Pd, and nickel) It is  $0.4 \leq x \leq 0.7$  or the magnetoresistance-effect head characterized by the thing of  $Zx \text{ Cr } 1-x$  (at least one sort,  $0 < x < 1$  as which Z was chosen from Mn, aluminum, Pt, Pd, Cu, Au, Ag, Rh, Ir, and Ru) included for any one sort least.

040] The magnetoresistance-effect head of invention of the 4th of this invention The huge magnetoresistance-effect film which has an antiferromagnetism layer for fixing the magnetization of the aforementioned magnetization fixing layer which has been arranged through a nonmagnetic interlayer, and by which the laminating was carried out at least the magnetization fixing layer and the magnetization free layer of a couple, and the aforementioned magnetization fixing layer, In the magnetoresistance-effect head which has the electrode of the couple for supplying current to the aforementioned huge magnetoresistance-effect film, and the vertical bias layer of the couple to the aforementioned huge magnetoresistance-effect film It comes to carry out antiferromagnetism combination of the ferromagnetic layer of the couple which the aforementioned magnetization fixing layer becomes from the ferromagnetic layer B by the side of the ferromagnetic layer A by the side of the aforementioned nonmagnetic interlayer, and the aforementioned antiferromagnetism layer through a magnetic coupling layer. The electrode of the aforementioned couple is a magnetoresistance-effect head characterized by having an electrode spacing narrower than the interval of the aforementioned vertical bias layer.

041] In addition, the composition of the 1st or 4th magnetoresistance-effect head mentioned above is also applicable composition of a magnetoresistance-effect element as it is.

042] Moreover, the magnetic disk drive equipment of this invention is characterized by providing the magnetoresistance-effect head of the above-mentioned this invention. And invention of the magnetic disk drive equipment of this application is characterized by having the mechanism in which magnetization of the aforementioned magnetization fixing layer is made to fix in the predetermined direction, using the magnetic field generated by applying current to the aforementioned magnetoresistance-effect element of the magnetoresistance-effect head of the above-mentioned this invention.

043] Furthermore, the manufacture method of the magnetoresistance-effect head of this invention is after membrane formation of the aforementioned huge magnetoresistance-effect film, and before it performs patterning, it is characterized by performing heat treatment among a magnetic field and making the direction of magnetization fix in the predetermined direction to the aforementioned ferromagnetic layer A and the aforementioned ferromagnetic layer

044] On the other hand, the magnetoresistance-effect element based on other forms of this invention The spin bulb film which has at least the two-layer magnetic layer arranged through the nonmagnetic interlayer of at least one layer, and the aforementioned nonmagnetic interlayer, In the magnetoresistance-effect element possessing the electrode of the couple which supplies sense current to the aforementioned spin bulb film the aforementioned spin bulb film The improvement layer in the magnetoresistance effect which turns into the aforementioned nonmagnetic interlayer of the aforementioned magnetic layer from the cascade screen of two or more metal membranes which touch the field of an opposite side, It has the non-magnetic layer which has the ground function or protection feature which touches the aforementioned magnetic layer of the aforementioned improvement layer in the magnetoresistance effect with the field of an opposite side. And it is characterized by the element which mainly constitutes the metal membrane which touches the aforementioned magnetic layer among the aforementioned improvement layers in the magnetoresistance effect not dissolving with the element which mainly constitutes the aforementioned magnetic layer.

045] The magnetoresistance-effect element of this invention With or the nonmagnetic interlayer of at least one layer the magnetoresistance-effect element possessing the spin bulb film which has at least the two-layer magnetic layer arranged through the aforementioned nonmagnetic interlayer, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film The aforementioned spin bulb film has the improvement layer in the magnetoresistance effect which turns into the aforementioned nonmagnetic interlayer of the aforementioned magnetic layer from the metaled monolayer or metaled cascade screen which touches the field of an opposite side. And while the element which mainly constitutes the aforementioned improvement layer in the magnetoresistance effect does not dissolve with the element which mainly constitutes the aforementioned magnetic layer which the aforementioned improvement layer in the magnetoresistance effect touches, the aforementioned improvement layer in the magnetoresistance effect is characterized by having the alloy layer of a noble-metals system at least.

046] The magnetoresistance-effect element of this invention With or the nonmagnetic interlayer of at least one layer the magnetoresistance-effect element possessing the spin bulb film which has at least the two-layer magnetic layer

arranged through the aforementioned nonmagnetic interlayer, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film. While the aforementioned magnetic layer of at least one layer is arranged through the improvement layer in the magnetoresistance effect which has at least the cascade screen of two or more metals, and one side of an alloy layer. It is characterized by the element which has two or more ferromagnetics combined magnetically, and mainly constitutes the aforementioned improvement layer in the magnetoresistance effect of dissolving with the element which mainly constitutes the aforementioned ferromagnetic which the aforementioned improvement layer in the magnetoresistance effect touches.

0047] Here, in three sorts of above-mentioned magnetoresistance-effect elements, the improvement layers in the magnetoresistance effect are an interface with a magnetic layer, an interface in a cascade screen, an interface with a non-magnetic layer or the non-magnetic layer as a protective layer, etc., show the electronic specular reflection effect as an example of an effect, and, thereby, raise the magnetoresistance effect of a spin bulb film. Moreover, when a free layer becomes thin, high MR rate of change can be maintained by canceling dispersion diffusive in an electron and raising the permeability of rise spin by the improvement layer in the magnetoresistance effect here acting as a nonmagnetic quantity conductive layer mentioned above, and forming the interface of an ultra-thin free layer and a nonmagnetic quantity conductive layer with the combination of material [ \*\*\*\* / un-]. Since it is an interface [ \*\*\*\* / un-], with heat treatment etc., an interface is stable and can cancel decline in MR rate of change. The improvement layer in the magnetoresistance effect in this invention is not based only on the specular reflection effect, and control of the crystal structure of a spin bulb film, improvement in the magnetoresistance effect by reduction of a magnetostriction, etc. ring it about further so that it may explain in full detail behind.

0048] Moreover, in three sorts of above-mentioned magnetoresistance-effect elements, when the magnetic layer which the improvement layer in the magnetoresistance effect touches consists of Co or a Co alloy as concrete composition of the improvement layer in the magnetoresistance effect, it is characterized by including at least one sort of elements chosen from Cu, Au, and Ag. Moreover, when the magnetic layer which the improvement layer in the magnetoresistance effect touches consists of a nickel alloy, it is characterized by including at least one sort of elements chosen from Ru, Ag, and Au. The thing containing elements, such as Cu, Au, Ag, Pt, Rh, Ru, aluminum, Ti, Zn, Hf, Nd, and Ir, is applicable to the improvement layer in the magnetoresistance effect.

0049] When applying an alloy layer to the improvement layer in the magnetoresistance effect, as an alloy which constitutes it, an AuCu alloy, a PtCu alloy, an AgPt alloy, an AuPd alloy, an AuAg alloy, etc. are illustrated. Moreover, when applying a cascade screen to the improvement layer in the magnetoresistance effect, as for a cascade screen, it is desirable to have two or more metal membranes which have the relation of dissolution mutually. However, it is also possible to use the cascade screen of two or more metal membranes which have a non-dissolving relation.

0050] Furthermore, in three sorts of above-mentioned magnetoresistance-effect elements, this is arranged in contact with a magnetic layer, using a magnetic layer, and the cascade screen and alloy layer of a metal membrane which have a non-dissolving relation as an improvement layer in the magnetoresistance effect. Moreover, when a free layer becomes thin, high MR rate of change can be maintained by canceling dispersion diffusive in an electron and raising the permeability of rise spin also here by the improvement layer in the magnetoresistance effect acting as a nonmagnetic quantity conductive layer mentioned above, and forming the interface of an ultra-thin free layer and a nonmagnetic quantity conductive layer with the combination of material [ \*\*\*\* / un-]. Since it is an interface [ \*\*\*\* / un-], with heat treatment etc., an interface is stable and can cancel decline in MR rate of change. The interface of the improvement layer in these magnetoresistance effects and a magnetic layer is excellent in composition \*\*\*\*\* based on a non-dissolving relation, and this state is further maintained after a thermal process. Therefore, the improvement layer in the magnetoresistance effect can be effectively operated as a specular reflection film (interface reflective film), and contributes to the improvement in a property of a magnetoresistance-effect element greatly. Since the improvement effect of this magnetoresistance-effect property is not lost after a thermal process, it can offer the magnetoresistance-effect element excellent in thermal resistance. In other words, according to this invention, by the conventional spin bulb film, MR property spoiled by process annealing by the diffusion and mixing by the interface can keep it good after process annealing.

0051] As a modification of the magnetoresistance-effect element of this invention which was mentioned above At least the nonmagnetic interlayer of at least one layer, and the two-layer magnetic layer arranged through the aforementioned nonmagnetic interlayer, In the magnetoresistance-effect element possessing the spin bulb film which has the antiferromagnetism layer which fixes magnetization of at least one layer among the aforementioned magnetic layers, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film. The aforementioned antiferromagnetism layer is arranged in contact with the improvement layer in the magnetoresistance effect which has at least the cascade screen of two or more metals, and one side of an alloy layer. And the element with which the element which mainly constitutes the aforementioned improvement layer in the magnetoresistance effect

mainly constitutes the aforementioned antiferromagnetism layer, and the magnetoresistance-effect element for which it does not dissolve are mentioned.

[052] At least the two-layer magnetic layer arranged through the nonmagnetic interlayer of at least one layer, and the aforementioned nonmagnetic interlayer as other modifications, In the magnetoresistance-effect element possessing the spin bulb film which has the antiferromagnetism layer which fixes magnetization of at least one layer among the aforementioned magnetic layers, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film The aforementioned antiferromagnetism layer is arranged in contact with the improvement layer in the magnetoresistance effect which has at least the cascade screen of two or more metals, and one side of an alloy layer. And the magnetoresistance-effect element containing at least one sort of elements with which the aforementioned improvement layer in the magnetoresistance effect is chosen from Cu, Au, Ag, Pt, Rh, Ru, aluminum, Ti, Zr, Hf, Pd, and Ir is mentioned.

[053] the improvement layer in the magnetoresistance effect in this invention functions effectively also to improvement in the magnetoresistance effect based on control of not only the effect as high MR maintenance when the free layer by the specular reflection film and the stable interface is thin but the film fine structure, and the magnetostriction control which is the magnetosensitive layer which consists of Co system magnetic materials, such as CoFe alloy for example, Cu ground layer -- if independent -- for example, the lattice spacing of a CoFe alloy -- small becoming -- passing -- on the other hand -- Au ground layer -- if independent, the lattice spacing of a CoFe alloy becomes large too much On the other hand, by using a cascade screen and an alloy layer which were mentioned above, Co system magnetic materials, such as Co as a magnetosensitive layer, and a CoFe alloy, into a lattice spacing effective in a low magnetostriction, and let d (111) lattice spacing be the range of 0.2055-0.2085nm. A magnetoresistance-effect property improves also by such magnetostriction control.

[054] Furthermore, when aiming at improvement in a property of a spin bulb film, suppression of the atomic diffusion by the grain boundary etc. is effective. In order to suppress the atomic diffusion by the grain boundary, it is desirable to form the grain boundary of a spin bulb film big and rough, and to lower grain boundary density. Moreover, it is desirable that it is the structure which should also be called false single crystal film which is the usual not the grain boundary but so-called sub grain boundary which does not almost have a gap of the orientation within a field though the grain boundary exists. A small angle tilt boundary etc. is mentioned as an example of such a sub grain boundary. Also to formation of such a small angle tilt boundary, the improvement layer in the magnetoresistance effect of this invention is effective, by applying the improvement layer in the magnetoresistance effect which consists of the cascade screen and alloy layer of a metal membrane which was mentioned above, can carry out fcc (111) orientation of the spin bulb film, and can make a gap of the direction of crystal orientation between the crystal grain in a film surface less than 1 degrees. A magnetoresistance-effect property improves also by such crystal grain control of a spin bulb film.

[055] The magnetoresistance-effect element of this invention is a thing based on the technology of reducing magnetostrictions, such as a CoFe alloy mentioned above, by the Au-Cu alloy or the Au/Cu cascade screen. With or without the nonmagnetic interlayer of at least one layer In the magnetoresistance-effect element possessing the spin bulb film which has at least the two-layer magnetic layer arranged through the aforementioned nonmagnetic interlayer, and the electrode of the couple which supplies sense current to the aforementioned spin bulb film the above -- fcc (111) orientation of the magnetic layer from which the magnetization direction changes with external magnetic fields among two-layer magnetic layers even if few is carried out, and it is characterized by d (111) lattice spacing being 0.2055nm or more

[056] As for d (111) lattice spacing of a magnetic layer, in the magnetoresistance-effect element mentioned above, it is desirable that it is the range of 0.2055-0.2085nm. Moreover, the magnetic layer from which the magnetization direction changes with external magnetic fields consists of Co or a Co alloy.

[057] The magnetoresistance-effect element of this invention mentioned above is used for the magnetic head and the magnetic recording medium of this invention. That is, the magnetic head of this invention is characterized by providing the bottom magnetic-shielding layer, the magnetoresistance-effect element of the above-mentioned this invention formed through the bottom reproduction magnetic gap on the aforementioned bottom magnetic-shielding layer, and the top magnetic-shielding layer formed through the bottom reproduction magnetic gap on the aforementioned magnetoresistance-effect element.

[058] The magnetoresistance-effect element of the above-mentioned this invention by which the magnetic head of the c/play separate-type of this invention was formed through the bottom reproduction magnetic gap on the bottom magnetic-shielding layer and the aforementioned bottom magnetic-shielding layer, The reproducing head which has the top magnetic-shielding layer formed through the bottom reproduction magnetic gap on the aforementioned magnetoresistance-effect element, It is characterized by providing the recording head which has the aforementioned top magnetic-shielding layer, the communalized bottom magnetic pole, the record magnetic gap formed on the

forementioned bottom magnetic pole, and the top magnetic pole prepared on the aforementioned record magnetic gap.

0059] The magnetic-head assembly of this invention is characterized by providing the head slider which has the magnetic head of the rec/play separate-type of the above-mentioned this invention, and the arm which has the suspension in which the aforementioned head slider was carried. Moreover, the magnetic recording medium of this invention is characterized by providing the head slider equipped with the magnetic head of the rec/play separate-type of the above-mentioned this invention which reads a signal by the magnetic field which writes a signal in a magnetic-recording medium and the aforementioned magnetic-recording medium by the magnetic field, and is generated from the aforementioned magnetic-recording medium.

0060]

Embodiments of the Invention] Hereafter, it explains in detail, referring to a drawing about the gestalt of operation of this invention.

Gestalt : thin-film-izing of a free layer of the 1st operation) The gestalt of implementation of invention about "thin-film-izing of a free layer" is explained to the beginning.

0061] Before here explains the gestalt of operation of this invention, the technical problem about "thin-film-izing of a free layer" which this invention person has recognized in process in which it results in this operation gestalt is explained in full detail.

0062] In a magnetoresistance-effect element, as mentioned above, in addition to the rise of MR rate of change, the large improvement in sensitivity is realizable with thin film-ization (reduction of a  $M_s \cdot t$  product) of a free layer. If it says roughly, an output will increase in inverse proportion to the size of the  $M_s \cdot t$  product of a free layer. However, it became clear about thin-film-izing of a free layer that the following problems arise as a result of examination which this invention person performed uniquely.

0063] As the 1st problem, it is mentioned that the bias point design at the time of sense current energization is difficult. If the bias point comes in the center of a portion with the alignment-inclination of a transfer curve when the magnetic field which starts at the time of head operation all carries out a leg, it will be called the optimal bias state. However, if the thickness of a free layer becomes thin, since the inclination of a transfer curve will become steep, it becomes very difficult to have the bias point in the center of the alignment field of a transfer curve. If the bias point becomes bad, and the asymmetry (asymmetry) of a signal will come out or it will become still worse, it becomes impossible to completely take an output level.

0064] As the 2nd problem, if a free layer is thinned very much with the conventional technology, MR rate of change will produce the problem which falls sharply. Reduction of MR rate of change brings about the fall of a reproduction output.

0065] Drawing 7 is a conceptual diagram for explaining two problems enumerated above. That is, this drawing expresses the transfer curve of the magnetic head which used the magnetoresistance-effect element, and when a free layer is thick, this drawing (b) expresses this drawing (a), respectively, when a free layer is thin. Since the inclination of a transfer curve will become steep ( $H_s$  becomes small) and MR rate of change will decrease if a free layer becomes thin as mentioned above, drawing 7 shows that two problems that  $\Delta V$  becomes small arise.

0066] Among the above-mentioned problems, the problem especially about the bias point has not been easily recognized, even if the membrane structure was determined, but it reached to an extreme of design top difficulty. "a gap" which this invention person carried out modeled calculation this time, and was obtained on the result and experience -- an amendment -- the bias point was able to be judged by things The calculation technique of the bias point is described below.

0067] The bias point is shifted by various external magnetic fields which join a free layer. This shift can be approximated as the sum of 1. current magnetic field ( $H_{cu}$ ), the static magnetic field ( $H_{pin}$ ) from 2. pin layer, the layer joint magnetic field ( $H_{in}$ ) from the pin layer through 3. spacer, and the disclosure magnetic field ( $H_{hard}$ ) from 4. hard bias film. In the magnetic field of the above 1-4, the hard bias magnetic field of 4. is comparatively small. Then, this invention person inquired wholeheartedly paying attention to the sum of the magnetic field of the above 1-3. The formula of the bias point used this time is shown below.

0068]

$$p = 50 \times (H_{shift}/H_s) + 50 \quad (1-1)$$

$$H_{shift} = -H_{in} + H_{pin} \cdot H_{cu} \quad (1-2)$$

$$H_s = H_{dfree} + H_k \quad (1-3)$$

$$H_{dfree} = \pi^2 (M_s \cdot t)_{free} / h \quad (1-3-1)$$

$$H_{pin} = \pi^2 (M_s \cdot t)_{pin} / h \quad (1-4)$$

$$H_{cu} = \pi C_x I_s / h \quad (1-5)$$

$$I = (I1 - I3) / (I1 + I2 + I3) \quad (1-5-1)$$

Here, b.p. of a formula (1-1) is the bias point [%] observed this time. The rated-bias point is 50%, and if it includes to a margin, it can be called bias point with 40 - 60 usable%. If the bias point shifts from these values, asymmetry (asymmetry) cannot come out, or it will become impossible to completely take an output, in being severer.

0069] When asymmetry becomes +10% when the bias point becomes 40%, and the bias point becomes 60%, as for the relation between a bias point value and asymmetry, asymmetry becomes about -10%. As for the rated-bias point in this calculation, 30 - 50% becomes an optimum value not on 40 - 60% but on experience so that it may mention later.

0070] Drawing 8 is the graphical representation showing the relation between the bias point value on calculation, and the regenerative-signal wave of a head. At the time of 30 - 50% of bias point value, asymmetry is comparatively small, and shows a good signal wave form at it. If the bias point comes to the place shifted, asymmetry will become large so that drawing 8 may show, and it will become impossible however, to use practically from the range.

0071] Hshift is the sum [Oe] of each magnetic field which joins a free layer, as expressed with a formula (1-2). Hs is an inclination on a transfer curve, as drawing 7 also showed.

0072] Drawing 9 is explanatory drawing showing the relation of each of these magnetic fields.

0073] Hdfree is the anti-magnetic field of the free layer in a certain MR height length. h is MR height length [μm]. Hpin is a pin disclosure magnetic field which joins a free layer from a pin layer. (Ms\*t) free is the product of the total saturation magnetic field Ms of a free layer, and Thickness t, and pin(s) (Ms\*t) are the saturation magnetization of the pin layer (magnetic thickness of the pin layer of the upper and lower sides to the case of synthetic AF difference) of the network of a pin layer, and the product of thickness.

0074] Hcu is a current magnetic field which joins a free layer, and Is is sense current [mA]. The coefficient C in a formula (1-5-1) is the ratio of current diverging which flows in the layer of the upper and lower sides of a free layer.

0075] Drawing 10 is a conceptual diagram showing the current diverging I1-I3 which flows each class.

0076] In the calculation explained here, since it is easy, neither the influence of the ABS side edge section nor the influence of a shield is taken into consideration. the estimate of the bias point by the calculation which this invention person performed, and an actual head -- \*\* -- if -- it has become clear on experience that the bias point shifts to a way's of calculation minus side about about 10% If order plus-or-minus 10% takes the usable bias point into consideration from the place of the rated-bias point, it can be called the point of 30% - 50% of bias point value acquired by calculation good [ however ]. Therefore, at the time of the value of 30% - 50%, it can be judged that the practically good bias point was obtained on the bias point obtained by calculation as shown above.

0077] The spin bulb film known concretely below until now is taken for an example, and a trouble is explained in detail using the bias point formula mentioned above.

the example 1 of comparison: It is usually a spin bulb (with no spin-filter-less x synthetic AF).

a5/NiFe2/Co0.5/Cu2/CoFe2/IrMn7/Ta5 (a unit is nm) (1)

the above (1) expresses the laminated structure of a spin bulb, and expresses the element and thickness (nm) which constitute each class. This example of comparison is a film on extension of the conventional technology which made only the free layer thin by the spin bulb film conventionally [ so-called ]. The bias point was calculated in this film composition.

0078] In the bias point formula of - (1-1) (1-5) formula mentioned above, the current magnetic field of a formula (1-5) is difficult to ask especially. The reason is that it is difficult to ask for the current diverging ratio C of a formula (1-5-1). In a thin film, the specific resistance of each class is because the resistivity of bulk is remarkable and values differ in response to the influence of crystallinity, a current distribution, etc. Since calculation which as actually as possible \*(ed) it was performed, this invention person was able to ask for the current diverging ratio C with a sufficient precision by performing the following devices this time.

0079] In order to ask for the specific resistance of each class, some films changed to order plus-or-minus 2nm were produced, and the thickness of a layer and the relation of conductance which observe were extrapolated in a straight line and it asked for them to produce the spin bulb film of the above-mentioned composition, and ask for the specific resistance of a certain layer. The reason searched for such is that the actually based value does not become by the technique of asking for specific resistance by the monolayer of the thin film used well. In order to make influence of crystalline, and influence of a current distribution as small as possible, it became clear by examination of this invention person that it is most accurate to make it the material as practice even with the same up-and-down film, and to see the conductance difference in a minute thickness range which was mentioned above.

0080] Since not only the influence of crystalline is small, but the specific resistance of each class for which it asked by this technique includes the influence of a current distribution, precision becomes good considerably from the current diverging ratio C of the formula (1-5-1) for which it asked by the simple parallel conductor using the specific resistance of a monolayer. By adoption of this technique, precision is raised more and the conventionally difficult

urrent magnetic field can be expected now also by calculation.

0081] As a result of asking for the specific resistance of each class by the above technique, NiFe is 20micro omegacm. oFe is 13microomegacm. Spacers Cu are 8microomegacm. IrMn was set to 250microomegacm. Here, since specific resistance was not able to change rapidly by crystallization and the influence of a scaling object was not able to calculate an exact large value about Cap Ta, either, when thickness was thickened about Ta (tantalum) of a ground, it was assumed that it was 100microomegacm. It asked for the current diverging ratio of each class using these values, and the current magnetic field Hcu was calculated by the formula (1-5).

0082] Moreover, 25Oe(s) of an actual measurement were used as a value of Hin. Hpin was calculated by the formula (1-4).

0083] Since height length becomes short with this film composition while pin thickness has been thick, the disclosure magnetic field Hpin which joins a free layer from a pin layer becomes large and much current flows above the free layer bottom, the current magnetic field Hcu which joins a free layer is also large. Therefore, by the big current magnetic field Hcu, thinking as the design technique of the bias point will cancel and carry out bias point adjustment, and it will have big Hpin.

0084] When sense current is set to 4mA, the result of the bias point value calculated using the above-mentioned value is shown in Table 1.

Table 1: Bias point MR height 0.3micrometer obtained by calculation of film of example 1 of comparison 70%0.5 micrometers 61%0.7 micrometers As shown in Table 1 53%, in MR height of 0.3-0.5 micrometers, the bias point is 61 70%, and is exceeded rather than the value considered on calculation to be the optimal bias point value.

0085] Drawing 11 is a conceptual diagram showing the state of the bias point in this example of comparison. That is, when MR height is narrowed, it turns out that the bias point shifts to an anti ferro side (larger side than 50%). In order for mechanical polishing to perform MR height, dispersion will surely come out of it. Dispersion in such MR height shows that the yield becomes very bad. It originates in that this tends to adjust the bias point by the very unstable technique of canceling the big pin disclosure magnetic field Hpin by the big current magnetic field Hcu as expressed to rawing 11 if it says qualitatively.

0086] Moreover, the film of this example of comparison has a still more essential problem besides the bias point. It is that MR rate of change falls, when the ultra-thin free layer made into the object by this invention is adopted. As a fact which this invention person acquired experimentally, if the thickness of a free layer becomes thin, that MR rate of change after process heat treatment deteriorates extremely will pose a big problem. For example, after process heat treatment, it will decrease to MR rate of change being about 11% in as-depo (state [ having as-deposited : deposited ]) with the composition of the example 1 of comparison even in the size of the abbreviation half of 5.6% of MR rate of change, and as-depo. Now, the spin bulb film of high-density correspondence is unrealizable.

0087] furthermore, since all the thickness of each class is becoming thin in this spin bulb film, field resistance of a spin bulb film also becomes a big value about 30ohms, and is not practical from the point of an electrostatic discharge (ESD:Electric Static Discharge) It is because it becomes easy to happen the more the more the resistance of ESD is strong, as known well.

0088] The above thing shows that there is simply nothing by practical film by which the film of the example 1 of comparison is adopted as the head for high-density record.

the example 2 of comparison: U.S. Pat. No. 5422591 (with no x synthetic AF with a spin filter)  
a5/Cux/NiFe1.5/Cu2.3/NiFe5/FeMn11/Ta5 (a unit is nm) (2)

in order to improve MR in an ultra-thin free layer, the spin bulb film of composition of having carried out the laminating of the high conductive layer to the free layer in the spacer non-magnetic layer and the opposite side is proposed. For example, patent No. 2637360, U.S. Pat. No. 5422591, U.S. Pat. No. 5688605, etc. can be mentioned.

0089] The film of the above (2) is the example of a spin bulb film based on U.S. Pat. No. 5422591. In this spin bulb film, in the spacer Cu of a free layer, since it will become a simple shunt layer by thickening Cu \*\* which touched the opposite side if the mean free path of rise spin is long, MR rate of change goes up by the bird clapper and Cu \*\* is thickened more than a mean free path, it has the inclination to take the peak of MR rate of change by a certain Cu \*\*. If this phenomenon is used, a part of reduction of MR rate of change in the ultra-thin free layer which was one trouble in the example 1 of comparison is improvable.

0090] However, by the spin bulb film of the above (2) based on U.S. Pat. No. 5422591, it has film composition which is called the thermal resistance of the bias point and MR rate of change and which has a problem at two points.

0091] First, about the viewpoint of the bias point, a direct publication or an indirect suggestion are not indicated at all in the specification of U.S. Pat. No. 5422591. And the film of (2) is composition which is not employable with an actual head at all. The reason is explained in full detail below.

0092] The current magnetic field Hcu was first computed using the specific resistance of each class experimentally

obtained by the completely same method as the example 1 of comparison. As resistivity of each class at that time, Ta is assumed that they were 100microomegacm and, as for 20microomegacm and Spacer Cu, in FeMn, 250microomegacm and NiFe used the value which was able to be found as experimentally [ 8microomegacm and Ground Cu ] as 3microomegacm. Moreover, sense current was set to 4mA. Although there was no description about  $H_{in}$ , 15Oe-25Oe as obtained as a result depended on this invention person's supplementary examination. Therefore,  $H_{in}$  was set to 20Oe(s) here.

1093] Element size calculated the bias point about the case of the head for high-density at the time of width-of-recording-track  $T_w=0.5\mu\text{m}$  and MR height= $0.3-0.5\mu\text{m}$ . The result is shown in Table 2.

1094] Table 2: the bias point [ ] MR height obtained by calculation with the composition of the example 2 of comparison at the time of changing ground Cu \*\* -- 127% 140%, with this composition, the pin disclosure magnetic field  $H_{pin}$  which joins a free layer from a pin layer is very large, and is the composition that the bias point tends to shift to a plus side Cu 0nm Cu 1 nm Cu 2nm0.3micrometer 126% 143% 156%0.5 micrometer 111% As the calculation result of the bias point of Table 2 also shows, in the case where ground Cu \*\* which does not use the spin-filter effect is zero, it turns out that it has come by height of 0.3-0.5 micrometers to the place when the bias point cannot completely take an output with 111% - 126%.

1095] Drawing 12 is a conceptual diagram showing the relation between the size of  $H_{in}$  when seeing in a transfer curve,  $H_{pin}$ , and  $H_{cu}$ , and the bias point. Since  $H_{pin}$  is large, it comes to the place which the bias point exceeded considerably by the current zero state, and becomes the design which is going to have it to the way of 50% somehow by the current magnetic field. However, with this composition, since Cu which is a high conductive layer is used for the ground, I3 in drawing 10 will become large, and the current magnetic field  $H_{cu}$  acquired by the formula (1-5) will become small. That is, to big  $H_{pin}$ , the bias point will be pulled down to about 50% by  $H_{cu}$  with a small retrose, and it will be difficult to have the bias point in the good point. Furthermore, Table 2 shows signs that the bias point becomes still worse as ground Cu \*\* is raised.

1096] As a result of repeating the above examination, with composition which has a publication in a Gurney patent, it became clear by being unable to perform a bias point design at all, but preparing Cu of a high conductive layer in a round that the bias point becomes still more unreal composition.

1097] Furthermore, the film of U.S. Pat. No. 5422591 is not a practical film, in view of the viewpoint of the thermal resistance of MR rate of change. Surely the value of MR rate of change in as-depo rises according to the spin-filter effect, as U.S. Pat. No. 5422591 has a publication. However, when an ultra-thin free layer was used after heat treatment which simulated the actual head production process, this invention person found out that the value of MR rate of change decreased remarkably as a characteristic phenomenon. This poses a serious problem, in order to obtain the high power for high-density record.

1098] Actually, if that whose MR rate of change was 1.8% in as-depo when it retested with the film (film of the above (1)) of the example of a Gurney patent and ground Cu \*\* was 1nm performs heat treatment which simulated this invention person's process, it will deteriorate to 0.8%. This main cause is because FeMn is used for the antiferromagnetism film so that it may state later. MR rate of change returned to the high value according to the spin-filter effect with much trouble is made to completely function in this in the spin bulb film using the ultra-thin free layer difficult for realizing high MR value. That is, in order to realize the ultra-thin free layer spin bulb film in which high MR rate of change is shown, it turns out that it cannot attain only by the simple spin-filter effect.

example 3 of comparison: JP,10-261209,A

a5/Cu3/Ta1/NiFe5/Cu2.5/Co2.5/FeMn10/Ta5 (3 (a unit is nm))

is not a thing aiming at the spin-filter effect of MR rate of change like U.S. Pat. No. 5422591 shown in the example 2 of comparison, and a current magnetic field  $H_{cu}$  reduces, and Cu shunt layer which approaches a free layer through Ta suppresses change of the bias point by sense current, and aims at stabilizing asymmetry by the film of the above (3) currently indicated by the JP,10-261209,A specification. However, like the film of (3), although such the way of linking is effective enough in the field where a free layer is comparatively thick, it does not serve as a practical film at all in respect of the bias point and MR rate of change at the time of the ultra-thin free layer used as the target by this invention. The reason is explained below.

1099] First, as the film of (2) of the example 2 of comparison showed, when  $H_s$  becomes very small about the bias point using an ultra-thin free layer, even if it reduces the current magnetic field  $H_{cu}$ , if the pin disclosure magnetic field  $H_{pin}$  is large, the optimal bias point cannot be realized. When  $H_s$  is comparatively big and the optimal bias point is once obtained thickly [ a free layer ] that is, the point that the sense current dependency of the bias point is small has the effective structure of the above (3). However, when a free layer becomes ultra-thin with the film composition of the above (3), the optimal bias point cannot be realized primarily. That is, in order to make it densification correspondence by the film of the composition of (3), when a free layer is set to 4.5nm or less, the bias point will shift to a plus side.

100] In order to show that, the bias point in the film of this composition of having asked by calculation is shown in able 3.

101] Table 3: The bias point MR height in film of example of comparison (3) NiFe 5nm NiFe 3nm0.3micrometer 5% 108%0.5 micrometers 83% 104%0.7 micrometers 81% As Hin, the value of 10Oe was used 100% here. It turns out that the bias point has shifted to the plus side by the film of the composition of the example of comparison (3) even when NiFe thickness is 5nm primarily if Table 3 is seen, and the bias point exceeds in a plus side increasingly if free layer NiFe thickness becomes thin with 3nm although it is the composition which cannot say it as a good design.

102] Drawing 13 is a conceptual diagram showing the relation of the determination element of the bias point in this example of comparison. Since only the current magnetic field  $H_{cu}$  has been reduced while  $H_{pin}$  has been large as expressed to this drawing, in the place where the bias point has thin free thickness, it has composition which cannot be taken at all. That is, since the time of the place which added all current magnetic fields  $H_{cu}$ , layer joint magnetic fields  $H_{in}$ , and pin disclosure magnetic fields  $H_{pin}$  becoming zero is a rated-bias point point, even if it is going to bring a current pin center, large close to a free layer like the structure of the above (3) and is going to make only a current magnetic field into zero, it becomes the film design which is completely meaningless.

103] Furthermore, the point that high MR rate of change required for densification cannot be obtained as fault of the end point which the structure of the above (3) has can be mentioned. That is, in the structure of (3), since the material of comparatively high resistance is inserted between the high conductive layer and the free layer as a diffusion prevention layer, when it becomes an ultra-thin free layer, the spin-filter effect of MR which is obtained by the Gurney effect is no longer acquired. MR rate of change will fall by the film of the composition of a free layer which demonstrates power especially by this invention explained in full detail behind of (3) from a field 4.5nm or less.

104] Above, for the reason of two points, the structure of the above (3) is the way of thinking in the field where a free layer is comparatively thick strictly, and it turns out that it does not become practical film composition at all in an ultra-thin free layer.

105] The example 4 of comparison: Spin-filter-less x synthetic

FTa5/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (a unit is nm) (4) In this example of comparison, in order to raise a pin property, synthetic AF structure was adopted. Anti ferro distributor shaft coupling (antiferromagnetism combination) of the two-layer ferromagnetic layer through Ru (ruthenium) is carried out. On the other hand, the ferromagnetic layer of one of these has fixed to \*\* with the antiferromagnetism film. By adoption of synthetic AF structure, with normal pin structure, it becomes possible to use, if there is a certain amount of size on the other hand even when the tropism anisotropy field  $H_{ua}$  is small, and pin thermal resistance improves. Moreover, as already stated, with synthetic AF structure, each other [ layer / ferromagnetic / of the upper and lower sides through Ru ] magnetization direction has turned to the retrose, and since the joint magnetic field is far larger than the medium magnetic field at the time of Number kOe and head operation, as for the magnetization moment which comes out outside, the difference of  $M_s \cdot t$  of an up-and-down pin layer is considered to be the moment of a network in approximation. That is, it becomes possible to make small influence of a \*\*\*\*\* pin disclosure magnetic field at a free layer, and the bird clapper is advantageously expected on the bias point (JP,7-169026,A).

106] For example, in the case of the example of comparison, it is thought with a 0.5nm pin layer that pin \*\* of a network is equivalent, and a pin disclosure magnetic field equivalent to an unrealizable thin pin layer can be realized with normal pin structure. Ideally, if an up-and-down pin layer is arranged with the same  $M_s \cdot t$  product, a pin disclosure magnetic field will be called zero. Only by reducing such a pin disclosure magnetic field, it was thought that the bias point design of a densification correspondence spin bulb film was enough. However, in the ultra-thin free layer of high-density correspondence, this invention person found out that the bias point stabilized only with synthetic AF structure was unrealizable this time. The content is explained below.

107] Drawing 14 is a conceptual diagram showing the relation of the determination element of the bias point in this example of comparison. That is, in the composition of this example of comparison, since the free layer is located in the place from which it separated greatly from the current pin center, large of the current distribution of a spin bulb film, the current magnetic field  $H_{cu}$  is very large. At most by about 20 Oes, it is in the state where current is not passed at all that the pin disclosure magnetic field is also very small by adoption of synthetic AF structure, and  $H_{in}$  is in the state of bias almost just. If current is passed by the spin bulb film of this composition, the more it passes current, the more it will shift from bias just by the big current magnetic field  $H_{cu}$ .

108] The result of the bias point calculation about this example of comparison is shown in Table 4.

109] Table 4: The bias point MR height obtained by calculation of film of example 4 of comparison  $H_{cu} \cdot H_{pin}$   $H_{cu} \cdot H_{pin} \cdot 0.3 \mu\text{m}$  88% 22%0.5 micrometers 80% 16%0.7 micrometers 73% The value of 20Oe(s) was used as  $H_{in}$  10% here. Table 4 shows that the bias point cannot realize 30 - 50% of value, whichever it passes current to the sense as expected.

0110] This is not desirable although a pin disclosure magnetic field is made small as much as possible, and it is got locked with this structure as a means to obtain bias just, and is equal in the pin thickness of the upper and lower sides with synthetic AF structure, that is, the technique which it has in bias just by the current magnetic field can be considered so that a pin disclosure magnetic field may be mostly made into zero, and  $H_{in}$  may be enlarged if possible and the big  $H_{in}$  may be canceled. It not only shifts the alignment field of an external-magnetic-field response simply, but big  $H_{in}$  brings about the bad influence which decreases an alignment field. Moreover, it is very difficult to control in by the small value uniformly, and it is not desirable that it is going to control by the big value uniformly naturally, and is going to produce a spin bulb film although it is good, even if it thinks from the point of mass production method.

0111] Moreover, since there is no high conductive layer in the spacer of a free layer, and the field of an opposite side, the time of an ultra-thin free layer, MR rate of change deteriorates in the completely same reason as the example 1 of comparison, and output sufficient as a head for high-density record cannot be secured. This is also an essential problem.

0112] As mentioned above, by the spin bulb film by adoption of only synthetic AF structure, it cannot perform realizing the ultra-thin free layer spin bulb film for high-density record at all from two points of the bias point and high power.

0113] As explained in full detail above, by the film of composition [ like the examples 1-4 of comparison ] whose this invention person is, the stable bias point and sufficient high power were clarified by performing the calculation and the trial production of a current magnetic field which were actually based [ that there is a problem that it cannot attain, and ] as a spin bulb film with the ultra-thin free layer for high-density record. And still more original trial production examination is carried out and it came to invent the composition explained in full detail below.

0114] Drawing 15 is the graphical representation expressed comparing the free thickness dependency of the bias point of the spin bulb film of each example of comparison mentioned above, and the spin bulb film by this invention. Any composition is known by that a big problem is in the bias point by the spin bulb film of each example of comparison known so far. Here, the optimal bias point is in 30 - 50% of range. And in order to fully obtain sensitivity, in low  $M_s \cdot t$ , it is necessary to obtain the bias point within the limits of this.

0115] On the other hand,  $M_s \cdot t$  has all separated from each example of comparison greatly from the range with the optimal bias point in low conditions. Furthermore, it turns out that the change of the bias point to  $M_s \cdot t$  is very large, and regulation of the bias point is difficult.

0116] On the other hand, the example 1 of this invention explained in full detail behind has the very small change of the bias point to  $M_s \cdot t$ , and it turns out that there is the bias point within the always optimal limits.

0117] In drawing 15, although the bias point on calculation has not said [  $M_s \cdot t$  ] 30% - 50% of range about the example 1 of comparison even place [ of 5 or more nmTs / big ], this is because it is a value with larger MR height length in low recording density for which  $M_s \cdot t$  uses the free layer of 5 or more nmTs in fact. It is because it is specifically a larger value than 0.3 micrometers - 0.5 micrometers of MR height length in the target recording density of this invention.

0118] Anyway, in the place where  $M_s \cdot t$  is the field of 5 or less nmTs, the dominance difference of a bias point design of the film of this invention and the film of the example of comparison is large, and a bird clapper is known clearly.

0119] In the structure of the examples 1-4 of comparison mentioned above, drawing 16 is a graphical representation showing how MR rate of change changes, when only  $M_s \cdot t$  of a free layer is made small. Here, MR rate of change of a vertical axis is an amount mostly proportional to the vertical axis of the transfer curve of drawing 9. The film of the examples 1 and 2 of this invention explained later was also shown for comparison.

0120] Here,  $M_s \cdot t$  of the film of the examples 1-4 of comparison and the film of the example 1 of this invention manufactured the sample which changed the NiFe thickness of a free layer, and the film of an example 2 created what changed the thickness of CoFe of a free layer. All of these values are the results after performing process annealing of 0 hours at 270 degrees C all over the magnetic field of 7kOe(s).

0121] Moreover, the high conductive layer of the example 2 of comparison and examples 1 and 2 was taken as Cu of nm of thickness. As  $M_s \cdot t$  of a free layer, the arrow showed the thing of the thickness of the free layer of the example of comparison all over this drawing. Moreover, as  $M_s \cdot t$  of a free layer,  $M_s$  of NiFe set to 1.8T and showed  $M_s$  of 1T and CoFe by the thickness of NiFe conversion of 1T altogether.

0122] By the film of the examples 1, 3, and 4 of comparison which do not have the high conductive layer which touches a free layer, if  $M_s \cdot t$  of a free layer becomes small, MR rate of change will deteriorate rapidly and it will become difficult to secure the high power dealing with densification.

0123] The thermal resistance of MR rate of change [ as opposed to / although the free layer  $M_s \cdot t$  dependency of MR rate of change is comparatively small, since FeMn which does not contain noble metals in an antiferromagnetism film

used by the film of the example 2 of comparison which has a high conductive layer / process heat treatment ] is a w. In such small MR rate of change, high power of densification is not securable.

0124] If 0.5nm Co or CoFe is inserted between Spacer Cu and the free layer NiFe, although it will become larger out 1 to 2% than the value in this drawing by the film of the example 2 of comparison, and the example 3 of comparison, the dependency over  $M_s \cdot t$  does not change with the case of the free layer of a NiFe monolayer, but is rough as MR rate of change in the place where  $M_s \cdot t$  of a free layer is small anyway. [ of a small value ]

0125] If the free layer which, on the other hand, has the high conductive layer which touched the free layer by this invention, and the antiferromagnetism film which has noble metals are used, the thermal resistance of MR rate of change to process heat treatment can also be improved, and sufficient high power of high-density correspondence can be obtained. The difference of MR rate of change with the example of comparison is large, and a bird clapper is known in the place which became smaller than 5nmT especially.

0126] Below, the magnetoresistance-effect element of this invention is explained in detail.

0127] Drawing 1 is a conceptual diagram showing the cross-section composition of the magnetoresistance-effect element of this invention. That is, the magnetoresistance-effect element of this invention has the composition which carried out the laminating of the high conductive layer 101, the free layer 102, the spacer layer 103, the 1st ferromagnetic layer 104, the joint film 105, the 2nd ferromagnetic layer 106, and the antiferromagnetism film 107.

0128] The good bias point is realizable by realizing  $H_{pin} - H_{in} = H_{cu}$  by making  $H_{cu}(s)$ ,  $H_{pin}(s)$ , and all the  $H_{in}(s)$  into small value by this composition, when  $H_s$  on the transfer curve by having thinned the free layer 102 very much specially is small. Furthermore, the head of high power is realizable by maintaining the thermal resistance of good MR rate of change for generally it being hard coming to realize high MR rate of change in the case of an ultra-thin free layer.

0129] That is, by spin bulb film composition of this invention, since the good bias point can be realized and high MR rate of change can be maintained even when it has an ultra-thin free layer for high-density, it is stabilized and high power can be obtained. Specifically, the good bias point is realizable by realizing  $H_{pin} - H_{in} = H_{cu}$  as a bias point design. It is important that  $H_{pin}(s)$ , and all  $H_{in}(s)$  and  $H_{cu}(s)$  make it small, in order to be stabilized and to realize the upper formula.

0130] First, by using the so-called synthetic AF structure which the 2nd ferromagnetic of the above combined in antiferromagnetism to  $H_{pin}$ , actually acting as  $H_{pin}$  becomes only what is depended on the difference of the two-layer magnetic thickness of the above 1st and the 2nd ferromagnetic, and it can reduce  $H_{pin}$ .

0131] It turns out that it is effective to reduce  $pin (M_s \cdot t)$  of a pin layer because of  $H_{pin}$  reduction even if this sees a formula (1-4).

0132] However, it is indispensable for it to be completely meaningless, even if it reduces only  $H_{pin}$  for the bias point design of an ultra-thin free layer, and to also reduce the current magnetic field  $H_{cu}$ . Therefore, by making the field of an opposite side carry out a nonmagnetic quantity conductive layer in contact with the spacer of a free layer, the center of the current distribution of current of flowing the inside of a spin bulb film can be brought close to a free layer, and it becomes possible to reduce  $H_{cu}$ . That is, in a formula (1-5) and a formula (1-5-1), when  $I_3$  increases at the time of a top type spin bulb film ( $I_1$  increases when it is a bottom type spin bulb film) and the current diverging ratio  $C$  falls, it is because the current magnetic field  $H_{cu}$  is suppressed. It is in high MR rate of change being maintainable as another big work of a nonmagnetic quantity conductive layer with the spin-filter effect at the time of the ultra-thin free layer made into the object by this invention. That is, the magnetization direction of the pin layer of the side which touches a free layer and a spacer can keep large mutually the difference of the mean free path of rise spin in the time of an parallel state and an anti-parallel state by preparing a nonmagnetic quantity conductive layer.

0133]  $H_{pin} - H_{in} = H_{cu}$  It is stabilized, and  $H_{in}$  reduction is also important in order to realize. Although it is important to make spacer \*\* thin for the high MR rate-of-change realization (the spin-filter effect) by the high conductive layer which touched the above ultra-thin free layers, generally  $H_{in}$  tends to become large, so that spacer \*\* becomes thin, and, so that a free layer becomes thin. It is important to conquer it and to use this invention by  $H_{in}$  of the range of about 0-20 Oes.

0134] Drawing 2 is the schematic diagram of the transfer curve obtained in the spin bulb film of this invention. Also in a transfer curve with small  $H_s$  using the ultra-thin free layer, since  $H_{pin}(s)$ , and all  $H_{cu}(s)$  and  $H_{in}(s)$  are reduced, the design of  $H_{pin} - H_{in} = H_{cu}$  is attained and the bias point has set it as about 50% of good place. Furthermore, since the spin-filter effect by the high conductive layer is also used, high MR rate of change can be maintained also in an ultra-thin free layer, and the vertical axis of drawing 2 has also realized the sufficiently large value.

0135] Next, each parameter of each element which determines the bias point, i.e.,  $H_{pin}$ , and  $H_{in}$  and  $H_{cu}$  is further explained to a detail.

0136] First, low  $H_{cu}$  is explained. As already explained, in this invention, by preparing a high conductive layer in the

de which touches the field of an opposite side, the value of C in a formula (1-5) is reduced, and the current magnetic field  $H_{cu}$  is reduced with the spacer of a free layer. It explains using the following film composition as a concrete example.

[137]

$a_5/Cu_x/CoFe_2/Cu_2/CoFe_{2.5}/Ru_{0.9}/CoFe_2/IrMn_7/Ta_5$  (a unit is nm)

Figure 3 is a graphical representation to which the spacer which is in contact with the free layer expresses the relation of the current magnetic field  $H_{cu}$  which joins the free layer to the thickness of the high conductive layer Cu of the opposite side in the above-mentioned film. Here, sense current was set to 4mA. The value of C of a formula (1-5) is small, and the current magnetic field  $H_{cu}$  is reduced by the bird clapper, so that the thickness of Cu is made to increase as shown in this drawing. When the current diverging ratio by the side of the upper layer and a lower layer becomes equal rather than a free layer, however the current magnetic field which joins a free layer may pass sense current, it turns into a zero magnetic field.

[138] Here, as for the thing of the point of this invention for which the current magnetic field  $H_{cu}$  is completely made to zero, it is not [ one ] conversely desirable but to reduce the current magnetic field. It sets to this invention and is  $H_{pin}-H_{in}=H_{cu}$ . It is because bias point adjustment becomes impossible like the example 3 of comparison mentioned above by the design which is going to carry out near of the current magnetic field to zero since bias point adjustment is performed by making it realized.

[139] When the thickness of a nonmagnetic quantity conductive-layer Cu layer is said in the big range, considering the viewpoint of a current magnetic field, within the limits of 0.5nm - 4nm will call it proper thickness. Since  $H_s$  becomes small so that the thickness of a free layer becomes thin, the one where the current magnetic field  $H_{cu}$  is also smaller becomes desirable. Here, as a nonmagnetic quantity conductive layer, although Cu was used, when using other metallic materials or a cascade screen, it can think by the thickness altogether converted into Cu. since the specific resistance for which it asked experimentally in the case of a nonmagnetic quantity conductive layer called  $Ru_{1.5}nm/Cu_{1nm}$  is [ 30microhm and Cu of Ru ] 10microhm -- Cu conversion --  $(1.5nm \times 10microhm) / 3microhm$  -- it will be said that it is equivalent to Cu thickness of  $+1nm = 1.5nm$

[140] as the specific resistance for which it asked experimentally when other metals were used similarly -- Cu -- 3microhm and Ir can use 20microhm, as for 30microhm and Au, Re can use the value to which in 3microhm and Pt 40microhm and aluminum say 12microhm to and 40microhm and Pd say 70microhm and Rh ] Os as 30microhm, and, as for 10microhm and Ag, 10microhm and Ru can ask for a current diverging ratio Moreover, when a nonmagnetic quantity conductive layer consists of an alloy, using the value of the above-mentioned specific resistance of the element of the principal component, it can calculate the thickness of Cu conversion and you may distribute proportionally according to composition of an element.

[141] Although the value of this specific resistance changes by the adjoining material as the example of comparison as explained, since the material which a nonmagnetic quantity conductive layer touches does not differ greatly, the value calculated using these values can prescribe proper thickness.

[142] Moreover, since  $H_{cu}$  is decided by the current diverging ratio of the upper layer and a lower layer to a free layer so that it may understand by the formula (1-5), a nonmagnetic quantity conductive layer has the thinner possible one desirable [ the thickness of a spacer layer located in a reverse side ] from a viewpoint of  $H_{cu}$  reduction. This [ the inclination's demanded from the spin-filter effect of MR rate of change of next explanation ] corresponds. Specifically, spacer thickness has 1.5nm - desirable about 2.5nm.

[143] The nonmagnetic quantity conductive layer has also achieved the function as a layer to bring about the spin-filter effect of MR rate of change with current magnetic field  $H_{cu}$  reduction. It originates in the effect and the range of thickness is also limited to some extent. For example, since considering the conduction electron which moves to the free layer side from a pin side it becomes desirable composition that a mean free path difference becomes [ the magnetization direction of a free layer ] large by parallel or anti-parallel at a pin layer, the thickness of the spacer independent of the rise of spin and a down has the thinner desirable one. When it will be called the thickness which is the grade to which  $H_{in}$  does not increase, spacer \*\* has 1.5nm - desirable about 2.5nm.

[144] Moreover, free thickness is thick and its one sufficiently thinner than the mean free path of rise spin is more desirable than the mean free path of down spin. For example, since it is about 1.1nm, as thickness of NiFe, when it is CoFe, 1nm - about 3nm is the most desirable [ the mean free path of the down spin of NiFe / 1nm - its about 4.5nm is the most desirable, and ]. Although the optimal thickness changes with pin \*\*, spacer \*\*, and free thickness in high electric conduction thickness, the peak of the thickness of the high electric conduction thickness which takes the peak of MR is carried out to the thick-film side, so that free thickness is so thin that spacer \*\* is thin. for example, a pin layer --  $CoFe_{2.5}nm$  and Cu spacer -- thick -- free 2nm -- the case where Cu is used for a high conductive layer when it is thickness  $CoFe_{2nm}$  -- about 2nm, by the way, a peak is taken Since the peak of MR rate of change is taken when the

thickness of a free-on experience layer and the total thickness of the nonmagnetic quantity conductive layer Cu are set about 4-5nm, it is desirable to set up the thickness of a nonmagnetic quantity conductive layer so that it may become near. When Cu is used for the nonmagnetic quantity conductive layer which touches a free layer, the total thickness of Cu thickness and free layer thickness serves as a range with 3nm - desirable about 5.5nm also including a margin.

[145] Next, H<sub>pin</sub> is explained. efficiency pin  $\frac{H_{pin}}{Ms \cdot t}$  [ in CoFe whose B<sub>s</sub> is 1.8T ] in order to reduce H<sub>pin</sub> -- about 2nm or less (it is 3.6nm or less by NiFe conversion), and a still more desirable efficiency-pin -- thick -- it is desirable to make 1nm or less (for it to be 1.8nm or less by NiFe conversion) As a realization means of the pin layer, synthetic AF structure is desirable. This consists of composition of an antiferromagnetism film / 1/Ru0.9nm of ferromagnetics / ferromagnetic 2, and is carrying out magnetic coupling of a ferromagnetic 1 and the ferromagnetic 2 in antiferromagnetism. While joined together in antiferromagnetism and, on the other hand, magnetization fixing of the ferromagnetic 1 is carried out with the antiferromagnetism film at  $\frac{H_{pin}}{Ms \cdot t}$ . the magnetization direction of a ferromagnetic 1 and a ferromagnetic 2 -- a retrose -- the joint magnetic field -- several -- kOe and since it is large, the difference of  $\frac{H_{pin}}{Ms \cdot t}$  of a ferromagnetic 1 and  $\frac{H_{pin}}{Ms \cdot t}$  of a ferromagnetic 2 is considered to contribute to an efficiency pin disclosure magnetic field as primary approximation (JP,7-169026,A)

[146] For example, with composition called IrMn/CoFe2/Ru0.9/CoFe2.5 (the unit of thickness is nm), efficiency pin  $\frac{H_{pin}}{Ms \cdot t}$  will call it 2.5nm-2nm=0.5nm (magnetic thickness is 0.9nmT(s)). If efficiency pin thickness can be reduced, H<sub>pin</sub> can be reduced as shown in a formula (1-4). Thus, synthetic AF structure is structure indispensable for mastering an ultra-thin free layer in respect of the bias point of this invention.

[147] Next, H<sub>in</sub> is explained. When said from the point of the bias point and the spin-filter effect, it was already said that it is desirable to make it as thin as possible as for Cu layer thickness used as a spacer. As a concrete value of H<sub>in</sub> in such thin thickness, it is desirable to hold down to about 5-15 Oes still more desirably zero to 20 Oe. As the one solution method of this invention, even when a spacer is thin, bilayer ground composition etc. is raised as film composition which does not increase H<sub>in</sub>.

[148] Next, the thermal resistance of MR rate of change is explained. When an ultra-thin free layer is used, it also becomes remarkably difficult to maintain the thermal resistance to process heat treatment of MR rate of change. Specifically, in order to improve MR rate-of-change thermal resistance of an ultra-thin free layer spin bulb film, it divides greatly and there are two measures. It is preparing the nonmagnetic quantity conductive layer more than [ with one of them ] fixed in contact with a free layer. Although the nonmagnetic quantity conductive layer, of course, also had a role of a spin-filter effect, it became clear to also play the role of raising the thermal resistance of MR rate of change. Although the thickness of a free layer was not so remarkable, when, as for this, it became thin by about 4.5nm or about 2nm, 1nm or more was understood are indispensable as total thickness of a nonmagnetic quantity conductive layer. For example, although it will decrease about 50% by the relative ratio at MR rate of change of as-depo, and MR rate of change after process heat treatment (270 degree-Cx 10 hours) when a nonmagnetic quantity conductive layer is 1nm, it can hold down to 0 - 30% of reduction by preparing an about 1nm nonmagnetic quantity conductive layer.

[149] Furthermore, dispersion is still in the rate of heat deterioration of MR rate of change only now. This cause is the difference of the antiferromagnetism film material which is the 2nd measure. As an antiferromagnetism film, the time of using FeMn etc. is the case of the 30% of the above-mentioned rates of heat deterioration. However, when using IrMn as an antiferromagnetism film material, it can be made to decrease to 0 - 15% of rate of degradation. Furthermore, although MR rate of change of as-depo cannot be measured when using PtMn, it is realizable in general, 10% of values of heat deterioration, i.e., the rate, of MR rate of change of IrMn. [ of as-depo ] This was dependent on whether the noble-metals concentration of antiferromagnetism film material is included, and the desirable thing made it clear especially on the spin bulb film of an ultra-thin free layer according [ using the antiferromagnetism film containing noble metals like IrMn, PtMn, PdPtMn, and RuRhMn ] to this invention.

[150] Drawing 4 is a graphical representation showing the concrete range of the pin thickness of synthetic AF for setting asymmetry blocked and realizing bias point 30%-50% -10% to +10%, as the above conclusion, and nonmagnetic quantity electric conduction thickness. Here, it is defined as  $(V1-V2)/(V1+V2)$  with "asymmetry, i.e., wave asymmetry", " with the absolute value V1 of the reproduction output in a right signal magnetic field, and the absolute value V2 of the reproduction output in a negative signal magnetic field. Therefore, it corresponds to asymmetry is -10% - +10%" being " $(V1-V2)/(V1+V2)$  the value of /  $(V1+V2)$  is 0.1 or less 0.1 or more minus plus."

[151] H<sub>pin</sub>-H<sub>in</sub>=H<sub>cu</sub> In order to realize, you also have to lower H<sub>cu</sub>, when H<sub>pin</sub> becomes small. That is, as shown in formula (1-4) and (1-5), it is the pin thickness (M<sub>s</sub>·t) (when pin is made small, thickness of a nonmagnetic quantity conductive layer must be thickened and pin (M<sub>s</sub>·t) is made into a larger value, you have to make thickness of a nonmagnetic quantity conductive layer thin.) of the upper and lower sides of synthetic AF.

[152] Specifically, when thickness of t<sub>m</sub> (pin2) and a nonmagnetic quantity conductive layer is set to t (HCL) (it converted into Cu layer of specific resistance 10microhmcm) for the thickness of t<sub>m</sub> (pin1) and a thin pin layer, the

ickness of the thick pin layer which forms synthetic AF. The place with which are satisfied of  $0.5 \text{ nm} \leq t_m(\text{pin}1) - t_m(\text{pin}2) + t(\text{HCL}) \leq 4 \text{ nm}$  and  $t(\text{HCL}) \geq 0.5 \text{ nm}$  is the range of this invention.  $0.5 \text{ nm} \leq t_m(\text{pin}1) - t_m(\text{pin}2) + t(\text{HCL})$  is the limitation that the bias point becomes about 30% that is, and asymmetry becomes +10% here, and  $t_m(\text{pin}1) - t_m(\text{pin}2) + t(\text{HCL}) \leq 4 \text{ nm}$  is the limitation that the bias point becomes about 50% that is, and asymmetry becomes -10%.

[153] Here,  $t_m(\text{pin}1) - t_m(\text{pin}2)$  is the magnetic thickness when converting into NiFe whose  $M_s$  is 1T, for example, it will be called  $x(2.5-2)1.8T = 0.9 \text{ nm}$  at the time of the synthetic AF structure of the composition of  $\text{PtMn}/\text{CoFe}_2 / \text{Ru}0.9/\text{CoFe}2.5$ . Moreover, in the case of the monolayer pin structure of the example of comparison shown for comparison,  $(M_s \cdot t)$  of a monolayer pin layer is used.

[154] Moreover,  $t(\text{HCL})$  is the case where a nonmagnetic quantity conductive layer is made into the thickness of Cu conversion, and when using nonmagnetic quantity conductive layers other than Cu, it can be made into the thickness of Cu conversion using the resistivity mentioned above.

[155] Moreover,  $t(\text{HCL}) \geq 0.5 \text{ nm}$  of lower limits of the thickness of a nonmagnetic quantity conductive layer required for high MR realization in a free layer thinner than  $4.5 \text{ nm}$  is specified. Moreover, if the thickness of a nonmagnetic quantity conductive layer is set to  $3 \text{ nm}$  or more, since  $\Delta R_s$  may fall as a still more desirable range of the above-mentioned range,  $t(\text{HCL}) \leq 3 \text{ nm}$  is desirable. Moreover, if the difference of the vertical pin thickness of synthetic AF is set to  $3 \text{ nm}$  or more, since the thermal resistance of magnetization fixing of a pin layer will deteriorate, it is desirable that it is  $t_m(\text{pin}1) - t_m(\text{pin}2) \leq 3 \text{ nm}$ .

[156] In drawing 4, the data of the film of the examples 1-4 of comparison mentioned above and the example 1 of this invention explained in full detail behind were plotted. Here, in the case of synthetic AF structure, the pin layer by the side of a spacer layer turned on the magnetic thickness of pin layer of horizontal axis plus-side, when magnetic thickness was thicker than another pin layer, and the pin layer by the side of a spacer layer decided to take the magnetic thickness of the pin layer of a horizontal axis to a minus side, when magnetic thickness was thinner than another pin layer. It decided to take all the magnetic thickness of a pin layer at a plus side in the case of the conventional pin layer which does not use synthetic AF.

[157] As shown in this drawing, although it separates from all the examples of comparison from the good range and asymmetry is bias bad, that is, large, according to this invention, the good bias point, i.e., a film with small asymmetry, is realizable.

[158] The concrete film composition which conquered the heat-resistant difficult point of the bias point design by this invention explained above which cancels small  $H_{\text{pin}}$  by synthetic AF by small  $H_{\text{Cu}}$ , that is, realizes  $H_{\text{pin}} - H_{\text{in}} = H_{\text{Cu}}$ , and MR rate of change peculiar to an ultra-thin free layer spin bulb film is shown.

Example 1) Top SFSV (NiFe/Co(Fe) free layer)

$\text{a}5/\text{Cu}x/\text{NiFe}2/\text{CoFe}0.5/\text{Cu}2/\text{CoFe}(2+y)/\text{Ru}0.9/\text{CoFe}2/\text{IrMn}7/\text{Ta}5$  (7-1) An antiferromagnetism film first explains the example of the so-called top type located in an upper layer side rather than a free layer of spin bulb film.

[159] Drawing 5 is the conceptual diagram showing the concrete film composition of the magnetoresistance-effect element of this example. That is, the laminating of the free layer 102 and the spacer layer 103\*\* was carried out the characteristic high conductive layer 101 by this invention, and on it on the ground buffer layer 12, the ferromagnetic in layer 104, 106 joined together in antiferromagnetism through 105, and, on the other hand, the pin layer of 106 has fixed to \*\* by the antiferromagnetism layer 107. The cap layer 113 is formed on the antiferromagnetism layer 107. The membrane structure of (7-1) is the thing of the type with which the free layer 102 consists of a cascade screen of the layer of 110 and 111, and the nonmagnetic quantity conductive layer 101 consists of a monolayer Cu.

[160] The film of (7-1) turns into a film which was compatible in MR and the bias point using the spin-filter effect of IR by Cu ground, the current magnetic field  $H_{\text{Cu}}$  reduction effect, and the  $H_{\text{pin}}$  reduction effect by synthetic AF. The result which calculated the bias point by the method mentioned above is shown in Table 5 about this film.

[161] Table 5 Bias point calculation result (a)  $y = 0.5$   $H_{\text{in}} = 20$  OeMR height  $x = 20.3$  micrometers 37%  $0.5$  micrometers 1%  $0.7$  micrometers 25% (b)  $y = 0.8$   $H_{\text{in}} = 20$  OeMR height  $x = 20.3$  micrometers 46%  $0.5$  micrometers 40%  $0.7$  micrometers 33% (c)  $y = 0.5$   $H_{\text{in}} = 10$  OeMR height  $x = 20.3$  micrometer 42%  $0.5$  micrometers 39%  $0.7$  micrometers

ground Cu \*\* could be  $2 \text{ nm}$  36% here. At the time of Cu ground of the monolayer which consists of a high conductive layer of a simple monolayer,  $H_{\text{in}}$  serves as  $20 \text{ Oe(s)}$  and a larger value a little. Then, the result of Table 5 (a) shows that the pin thick difference of synthetic AF shifts to a minus side a little from 40% of a good bias point value in  $0.5 \text{ nm}$ . Although it is a film also with this sufficiently practical, the case where  $y = 0.8 \text{ nm}$  and  $H_{\text{pin}}$  are increased a little is as a result of Table 5 (b). This enables it to bring the bias point close to a good value, when the bias point has shifted with some undershirt, as shown in Table 5 (a). Moreover, as shown in Table 5 (c), even if it lowers  $H_{\text{in}}$ , the bias point can be similarly made into a good value. Since the one where  $H_{\text{in}}$  is smaller will become [ the height dependency of the bias point ] small so that clearly if (c) is compared with Table 5 (a) and (b), as for  $H_{\text{in}}$ , decreasing as much as possible is desirable. Although  $H_{\text{pin}}$  becomes [ the smaller one ] small and a height dependency becomes small, the vertical pin

ick difference of synthetic AF structure With the about 0.3nm difference of (a) and (b), since it is almost influential  $y = 0-1\text{nm}$  ( $M_s t = 0 - 1.8\text{nmT}$  in NiFe) is desirable still more desirable, and the range of  $y = 0-0.5\text{nm}$  ( $0 - 0.9\text{nmT}$  in NiFe) with the bias point The improvement in a property of the cure against ESD-proof etc. is taken into consideration, and since adjustment of the value of  $y$  is possible, it is desirable.

162] Ground Cu \*\* also uses the spin-filter effect of MR with bias point adjustment. although Hcu will become small if ground Cu \*\* is thickened, in order that  $\Delta R_s$  may decrease -- Cu -- thick --  $0.5-3\text{nm}$  is especially desirably desirable  $0.5\text{nm} - 5\text{nm}$  the optimal thickness of the Shimoji Cu \*\* from which, as for ground Cu \*\* from which the spin-filter effect of MR is acquired, the spin-filter effect of MR is acquired for the time when free thickness is thinner depending on free lamination is shifted to the thicker one In the result obtained experimentally, when the sum of ground Cu \*\* and the thickness of a magnetic free layer is  $4\text{nm} - 5\text{nm}$ , MR rate of change takes peak value.

163] In the case of free lamination as shown in (7-1), the effect of  $R_s$  reduction by the increase in MR by the spin-filter effect according [ ground Cu \*\* ] to Cu thick increase and Cu thick increase cancels  $0-1.5\text{nm}$  exactly, and  $\Delta R_s$  does not almost have change in it. 1.  $\Delta R_s$  will decrease in  $5\text{nm} - 2\text{nm}$ , and  $\Delta R_s$  will decrease by  $0.25\text{ohms}$  in about  $0.1\text{ohms}$  and  $1.5\text{nm} - 3\text{nm}$ . Since the fall of  $\Delta R_s$  is proportional to loss of power mostly as it is, it is not desirable. however -- case it is desirable for ground Cu \*\* to thicken on the bias point -- this free lamination -- Ground Cu -- thick -- using  $3\text{nm}$  is also considered At this time, the current magnetic field per unit current is small, and since the spin bulb membrane resistance is also falling, it can consider the technique of recovering the loss of power by the fall of  $\Delta R_s$  by passing more current. It is because the amount of outputs is also proportional to the amount of current mostly. Since it increases 25% by setting for example, sense current to  $5\text{mA}$  from  $4\text{mA}$  of old calculation when  $\Delta R_s$  falls 10% by increasing ground Cu \*\*, 10 minutes is suppliable with the part of  $\Delta R_s$  fall.

164] When free thickness is thick NiFe<sub>4</sub>/CoFe<sub>0.5</sub> (nm), ground Cu \*\* has desirable about  $0.5-2\text{nm}$ , and when a free layer is thin NiFe<sub>1</sub>/CoFe<sub>0.5</sub>nm, ground Cu \*\* has desirable about  $1-4\text{nm}$ . Moreover, you may change the thickness of interface CoFe in  $0.3-1.5\text{nm}$ . Moreover, you may use Co or other Co alloys instead of CoFe. Since a soft magnetism cannot be realized in Co simple substance when using Co instead of CoFe, it is desirable to make it as thin as possible.

165] For example, when NiFe is  $4\text{nm}$ ,  $0-1\text{nm}$  and NiFe are  $2\text{nm}$  and  $0-0.5\text{nm}$  and NiFe are  $1\text{nm}$ ,  $0-0.3\text{nm}$  of Co is desirable. Moreover, when caring about interface diffusion with Ground Cu, you may insert Cu, and Co and CoFe of material [ \*\*\*\* / un-] also into an interface with Ground Cu. For example, free layers, such as Co<sub>0.3</sub>/NiFe<sub>2</sub>/Co  $0.5$  and CoFe<sub>0.5</sub>/NiFe<sub>2</sub>/CoFe<sub>0.5</sub>, can be considered.

166] Moreover, you may use the alloy free layer of NiFeCo instead of making it the cascade screen of such an ultra-thin magnetic film.

167] Moreover, in an ultra-thin free layer which is being made into the object by this invention, it also becomes difficult to realize a low magnetostriction. As one difficult point, the magnetostriction of NiFe is just large and a birdapper is mentioned, so that the thickness of NiFe becomes thin. although nickel<sub>80</sub>Fe<sub>20</sub> (at%) is usually sufficient as composition of NiFe in a free layer called NiFe<sub>8</sub> nm/CoFe<sub>1</sub>nm in order to conquer it -- the case of the free layer of  $4.5$  less nmTs of this invention -- nickel<sub>80</sub>Fe<sub>20</sub> -- nickel -- it is desirable to make it rich the time of NiFe thickness being specifically about  $4\text{nm}$  -- nickel<sub>81</sub>Fe<sub>19</sub> (at%) -- nickel -- the time of NiFe thickness being about  $3\text{nm}$  richly -- nickel<sub>81.5</sub>Fe<sub>18.5</sub> (at%) -- nickel -- it is desirable to make it rich As an upper limit of nickel concentration, nickel<sub>90</sub>Fe<sub>10</sub> (at%) grade is desirable.

168] As mentioned above, it is two big purposes the purpose of Ground Cu reducing the current magnetic field Hcu, and realizing the good bias point also in an ultra-thin free layer, and to use the spin-filter effect without degradation of MR rate of change also in an ultra-thin free layer.

169] If it says from the point of the bias point,  $y$  and  $x$  are not independently decided by the film of the above (7-1), and it will be cautious of a mutual value and it will be decided that it will be it. For example, since the current magnetic field Hcu which cancels it since Hpin will become small if  $y$  becomes small also has the smaller good one, the optimum point shifts the value of  $x$  to the way of a larger value.

170] Specifically, the following thickness designs can be considered as one example. When pin layers are  $2\text{nmT(s)}$ , as a design in case a nonmagnetic quantity conductive layer is a Cu layer, Cu layer  $0.5-1.5\text{nm}$ , When pin layers are  $0.5\text{nmT(s)}$ ,  $1-2\text{nm}$  and the pin layer of Cu layer are  $1\text{nmT(s)}$ ,  $1.5-2.5\text{nm}$  and the pin layers of Cu layer are  $0.5\text{nmT(s)}$ , and  $2-3\text{nm}$  and the pin layer of Cu layer are  $0\text{nmT(s)}$ , Cu layer will be called  $2.5-3.5\text{nm}$ .

171] When a pin layer is Co or CoFe here, the thickness of a pin layer is  $t = (M_s t)_{\text{pin}} / 1.8T$ . When [nm] and a pin layer are NiFe(s), pin layer thickness is  $t = (M_s t)_{\text{pin}} / 1T$ . It will be called [nm].

172] Spacer Cu may use the alloy containing Au, Ag, or these elements other than Cu etc. However, Cu is the most desirable. The realizing-high MR and ground side of a free layer has [ spacer thickness ] the thinner possible desirable one, in order to make the shunt layer of an opposite side as small as possible and to reduce a current magnetic field. However, since the ferro-magnetic coupling of a pin layer and a free layer will become strong and H<sub>in</sub> increase will

rise if too not much thin, about 1.8-2.3nm is desirable still more desirably 1.5nm - 2.5nm.

173] Although the ground quantity conductive layer which has played the big role for the spin-filter effect and current magnetic field reduction consists of Cu(s) of a monolayer here, you may form it by the cascade screen. For a certain reason, in a topspin bulb film, the role of the seed layer of fcc also has fcc or a hcp metallic material good at its time as furring. Specifically, the alloy layer of the metal which consists of Au, Ag, aluminum, Zr, Ru, Rh, Re, Ir, Pt, etc., or a cascade screen can be considered. although an effect is enough acquired with simple Cu ground if it is for the spin-filter effect of MR, and the current magnetic field reduction effect, there is a role which is two called magnetostriction control and  $H_{in}$  control of an ultra-thin free layer as an effect which makes furring an alloy layer and cascade screen purposely. Specifically, the following examples can be considered.

174] Ta5 / Ru1/Cu1.5 / NiFe2/CoFe0.5 / Cu2/CoFe2.5 / Ru0.9/CoFe2 / IrMn7/Ta5 (7-2) By using Ru1nm as a ground, membranous flat nature can improve and  $M_s \cdot t$  of a free layer can realize low  $H_{in}$  of about 10 Oes easily by spacer 2nm in spite of NiFe conversion 2.9nmT and an ultra-thin free layer. Realization of low  $H_{in}$  is desirable at the point as for which MR height dependency of the bias point becomes empty of being lost. Moreover, even if it does not give the thickness difference of the vertical pin layer of synthetic AF in vain, it is desirable also at the point that the good bias point is realizable. Although the thickness of Ru set to 1nm here, 1nm - about 3nm is desirable still more desirably 0.5nm - 5nm. The thickness with desirable material other than Ru does not change so much.

175] By the film of (7-2), when calculating  $H_{Cu}$ , it becomes addition of the electric shunt layer of the thickness of Ru and the thickness of Cu. the case of Ru -- the ratio of 30microomegacm and Cu -- in the viewpoint of eye an about 3 me hatchet of specific resistance, and  $H_{Cu}$ , the film of (7-2) will say that it is equivalent to a 1.8nm film by Cu thick conversion. However, in the viewpoint of MR, resistance is high in Ru, and most spin-filter effects are not acquired in touching NiFe direct and setting Ru to it, since the electronic mean free path is short. Therefore, as a layer which touches a free layer, Cu, Au, Ag, etc. of low resistance are desirable as much as possible, and material, such as Ru, is reasons with desirable making it a bilayer through Cu, Au, Ag, etc. This is one reason purposely made into a bilayer ground.

176] Moreover, although buffer layers Ta and Ru were divided and considered here, if Ru layer also demonstrates the effect as a buffer layer, there may not be a Ta layer. For example, it is also possible to lose Ta when using Zr layer or a change of Ru.

177] When using a buffer layer, Ti, Zr, W, Cu, Hf, Mo, or these alloys can be used other than Ta. Even if it uses which such material, 2nm - about 5nm of thickness is desirable still more preferably 1nm - 7nm.

178] Although IrMn (Ir:5 - 40at%) was used as an AF film here, as thickness of IrMn, 3nm - about 13nm is desirable. Since the noble metals which fit the narrow gap head towards densification since a pin property also within thickness good as a merit using IrMn is realizable are included, the feature that high MR rate of change is maintainable is after heat treatment. By the film used for the antiferromagnetism film, FeMn as shown in the example 2 of comparison is unmaintainable, after heat-treating high MR rate of change. This is a phenomenon which appears notably, when using an ultra-thin free layer like this invention.

179] Moreover, although CrMn, NiMn, and NiO may be used as an antiferromagnetism film, for high MR rate-of-change realization, AF containing a noble-metals element is desirable. For example, you may use Pd, Rh, etc. instead of Ir. Since MR rate of change improves compared with FeMn, NiMn, etc., high MR rate of change is maintained also after annealing heat treatment indispensable to a head. Moreover, it is also one of the desirable examples to use PtMn with the still higher concentration of a noble-metals element.

180]

Ta5/Cux/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (7-3)

Ta5/Rux/Cuy/NiFe2/CoFe0.5/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5(7-4)

as a merit using PtMn (Pt:40 - 65at%), since noble-metals concentration is still higher than IrMn, there can be still less MR degradation by process annealing, high MR rate of change can be realized,  $\Delta R_s$  can be enlarged, and it is mentioned that high power is obtained. In the spin bulb film of the ultra-thin free layer which the good thermal resistance of MR cannot realize easily, MR thermal resistance has the best combination of composition with the ground Cu by the spin-filter effect etc., and PtMn. You may use PdMn and PdPtMn instead of PtMn (noble-metals concentration : 40 - 65at%).

181] When it says from a viewpoint of MR thermal resistance, a certain thing of ground Cu \*\* is desirable 1nm or more. It is because the thermal resistance of MR will become bad if it is the thickness not more than it. However, at a certain time, the thickness of NiFe can secure 4nm or more of thermal resistance of MR, if there is 0.5nm or more of ground Cu \*\*.

182] Since PtMn is large at the value as IrMn also with the almost same value of electric specific resistance, the contribution to a current magnetic field is small desirable. Thus, the film of (7-3) and (7-4) is a film which was very

cellent practically.

183] However, since it is thicker than the case where the critical thickness out of which the 1 direction anisotropy would come as a demerit of PtMn is IrMn, it is mentioned that it is difficult to make it thin to about 5nm. Therefore, when PtMn is used, as thickness of PtMn, 5nm - 30nm is desirable. 7nm - about 12nm is desirable still more desirably. Also in PtMn, the view over bilayer-izing of the ground of a free layer as shown in (7-4) is completely the same.

184] (7-1) As a variation of the example of - (7-4), it is possible to carry out the laminating of the noble-metals element film further on an antiferromagnetism film. For example, you may use a monolayer or cascade screens, such as Al, Ru, Pt, Au, Ag, Re, Rh, and Pd. Low  $H_{in}$  is realizable also in the time of thin spacer thickness with this composition. However, if thickness becomes thick not much, since a current diverging ratio will increase in the upper layer side of a free layer, as total thickness of a monolayer or a cascade screen, 0.5nm - about 3nm is desirable.

185] As mentioned above about drawing 15, compared with the examples 1-4 of comparison, the spin bulb film of this example is far excellent in the controllability of the bias point, and can obtain the optimal bias point certainly.

186] Moreover, as mentioned above about drawing 16, the spin bulb film of this example can obtain high MR rate of change compared with the examples 1-4 of comparison.

Example 2) Top SFSV (simple CoFe free layer)

Example 1) Ta5/Cu<sub>x</sub>/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 (8-1)

Example 2) Ta5/Cu<sub>x</sub>/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 (8-2)

In this example, the simple free lamination which consists of a CoFe monolayer instead of a laminating free layer like NiFe/Co like (an example 1) or NiFe/CoFe as a free layer was used. That is, in drawing 1, it is the structure where the free layer 102 consists of CoFe of a monolayer, and the high conductive layer 101 consists of a monolayer Cu.

187] Although various difficult points arise in order to realize an ultra-thin free layer which realizes (5nmT in NiFe), in the CoFe system free layer which consists of a monolayer, there is a merit of being comparatively easy, from soft-magnetism control in an ultra-thin region being [ film composition ] a monolayer. You may add a thing like B, Cu, Al, Manganese, Rh, Pd, Ag, Ir, Au, Pt, Ru, Re, and Os as the 3rd alloying element to CoFe. However, by pure Co, a soft magnetism is unrealizable instead of a CoFe alloy. Co85Fe15at% - Co96Fe4at% of CoFe is desirable. This is depended on a viewpoint of magnetostriction control so that it may state later.

188] Moreover, as for a CoFe free layer, it is desirable to carry out fcc (111) orientation from a viewpoint of a soft magnetism. Although fcc (111) orientation is carried out and things are desirable so that resistance may become small, so from the point of acquiring the spin-filter effect effectively, the example of the free layer of microcrystal structure like CoFeB or amorphous structure is also considered.

189] Since  $M_s$  can be realized by thickness thin also for realizing the same  $M_s \cdot t$  from it being larger than NiFe, a simple CoFe free layer becomes advantageous also from a viewpoint of the spin-filter effect. For example, to total thickness becoming about 4nm by NiFe/CoFe NiFe3.6/CoFe0.5 (nm), for realizing the free layer of 4.5nmT(s), in a simple CoFe free layer, it is CoFe2.5nm and about 1.5nm is thinly made rather than NiFe/CoFe. If a high conductive layer is prepared in these both film in contact with the bottom of a free layer, although filter out of both film is carried out since it is thick compared with about 1nm which is the value of the mean free path of down spin, a down spin electron. Since it will become the mean free path of rise spin, and a near value if it becomes about 4nm of total thickness of NiFe/CoFe, the high conductive layer under it will bring about a simple shunt effect, and the more it thickens a high conductive layer, the more MR will reduce it under the influence of a shunt effect.

190] On the other hand, about simple CoFe, since the mean free path is longer than 2.5nm, the mean free path of rise spin becomes long, so that a certain amount of thickness attaches a high conductive layer, and MR goes up. When Cu is experimentally used for a high conductive layer and the total thickness of the free layer which consists of Cu layer, NiFe/CoFe, or a CoFe layer is about 4nm or 3nm - 5nm, taking MR peak is acquired experimentally. That is, by CoFe, although reduction in MR is brought about rather than the spin-filter effect in NiFe/CoFe for a shunt effect when there is required high conductive-layer thickness on a bias point design, since coexistence of the MR elevation effect can be aimed at with bias point adjustment, it becomes advantageous according to the spin-filter effect. The thickness of Cu layer which takes MR peak becomes a bird clapper thickly, and the combination effect of the spin-filter effect and the bias point adjustment effect comes out of this, so that CoFe thickness is thin as mentioned above, since MR peak value is decided by total thickness of a high conductive layer and a free layer. The simple CoFe free layer is more desirable by the spin-filter spin bulb by the above reason.

191] Since laminating NiFe/CoFe of MR thermal resistance is worse, since the simple CoFe free layer is larger, MR's is good.

192] The monolayer of CoFe is easier for control than NiFe/CoFe whose magnetostriction control is also the cascade screen of an ultra-thin layer. Especially, NiFe/CoFe whose one interface increases in an ultra-thin free layer since the interface magnetostriction is important is more disadvantageous.

193] The bias point in the composition of (8-1) as well as [ almost ] the case of an example 1 becomes within 30 - 40% of good limits. It is small like [ a height dependency ] an example 1.

194] Since the saturation magnetic field  $H_s$  on a transfer curve becomes small about the  $M_s \cdot t$  dependency of a free layer so that  $M_s \cdot t$  is small, stricter bias point adjustment is required. Since it becomes important to specifically reduce current magnetic field more, the need of making the thickness of a high conductive layer increasing comes out. By the spin bulb film by this invention, in order that the thickness of a high conductive layer in which MR peak appears according to the spin-filter effect may shift to the thicker one so that the thickness of a free layer becomes thin, as already stated, it turns out that the trend is in agreement and the design concept of the spin bulb film of this invention is its  $M_s \cdot t$  as a film of the head for high-density.

195] At the time of free layer  $M_s \cdot t$ -4.5nmT and 2.5nm of CoFe thickness, the good thickness of a high conductive layer by Cu conversion specifically 0.5nm - 4nm, At the time of 1nm - 3nm,  $M_s \cdot t$ -3.6nmT, and 2nm of CoFe thickness, they are Cu film conversion still more desirably. 1nm - 4.5nm is Cu film conversion still more desirably at the time of 1.5-3.5nm,  $M_s \cdot t$ -2.7nmT, and 1.5nm of CoFe thickness. Still more desirably, at the time of 2nm - 4.5nm,  $M_s \cdot t$ -1.8nmT, and 1nm of CoFe thickness, it is Cu film conversion and 1.5nm - 2nm - 5.5nm 5nm is set to 2.5nm - about 5nm still more desirably.

196] By (8-2), PtMn is used to using IrMn as an antiferromagnetism film in (8-1). By using PtMn, MR thermal stability improves further and the merit that improvement in an output can be aimed at is obtained. This is the same as that of the time of a NiFe/Co(Fe) free layer. However, since there is a trouble that  $H_{in}$  tends to go up [ the way when using PtMn ], in order to design the bias point at a good place, the cure of whether the current magnetic field  $H_{cu}$  is reduced, or either or both  $H_{pin}$  increase is more nearly required than the time of using IrMn. [ both ] In order to reduce  $H_{cu}$ ,  $\sigma$  of a high conductive layer is made to increase, that is, it can consider making the thickness of a high conductive layer increase. Moreover, in order to make  $H_{pin}$  increase, it is possible to make the pin layer membrane thickness difference of the upper and lower sides of synthetic AF slightly larger than the time of IrMn. However, since it so becomes causing the fall of  $\Delta R_s$ , adjustment in the range of about 0-2nm is more desirable [ making the thickness of a high conductive layer increase ] than the time of IrMn at Cu conversion in high conductive-layer thickness. Moreover, since it becomes also making MR height dependency of the bias point increase as stated so far, as for making  $\Delta R_s$  of synthetic AF structure increase, it is desirable to design by the increase in about 0-1nm by CoFe conversion compared with the time of IrMn desirably [ enlarging not much ]. The following composition is also considered as a variation of (8-1) and (8-2). Ta5/Ru/Cu/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/IrMn7/Ta5 Ta(8-3) Ru/Cu/CoFe2/Cu2/CoFe2.5/Ru0.9/CoFe2/PtMn10/Ta5 In this (8-4) composition, it constituted from a cascade screen called Ru/Cu instead of Cu monolayer as a high conductive layer. The reason made into a cascade screen is used on the following two reasons.

197] 1. About CoFe magnetostriction control of CoFe magnetostriction control 2.  $H_{in}$  reduction effect above-mentioned 1., it is going to control a magnetostriction by strain control of CoFe to explain in full detail behind. That is, when a simple Cu twist also extends the fcc-d (111) spacing of CoFe and a Co90Fe10 (atmic%) free layer is used, it is going to control near the zero the magnetostriction of the CoFe free layer which is easy to become large at a negative side. Therefore, as a material located under Cu layer, what has a larger atomic radius than Cu is desirable. For example, Fe, Au, Ag, aluminum, Pt, Rh, Ir, or Pd is [ other than Ru ] desirable. It is possible also by changing the CoFe composition other than the formation of a ground bilayer from 90-10 in a meaning called magnetostriction control. Specifically, the CoFe alloy free layer of the composition range of Co90Fe10-Co96Fe4 is used. It is because the effect of raising the flat nature at the time of film growth is in Ru about the  $H_{in}$  reduction effect of above-mentioned 2. on the other hand. As already stated,  $H_{in}$  is because it is desirable to carry out a bias point design by  $H_{cu}$  and  $H_{pin}$  in the narrowest possible place. especially, in SFSV, the thinner one is desirable as it cuts with the point which is two called current reduction of the spin-filter effect of MR, and the upper layer of a free layer gaily [ spacer thick ], and since the technology of mastering the ultra-thin spacer which is about Cu-2nm is required, generally the  $H_{in}$  control with a big spacer thick dependency becomes difficult By making it a Ru/Cu cascade screen, it can be called Ru1.5 nm/Cu1nm - 1nm ground, free layer  $M_s \cdot t$ 3.6nmT, an ultra-thin free layer called 2nm of CoFe thickness, and spacer Cu2nm, and low  $H_{in}$  called 7-13Oe can be realized as  $H_{in}$ . When it takes into consideration that  $H_{in}$  was about 20 Oes in the example of (7-1) and (7-2), this  $H_{in}$  reduction effect is large.

198] What is necessary is just to only convert into  $\sigma$  and Cu thickness from the specific resistance of Ru, when seen from a viewpoint of  $H_{cu}$  calculation. Since the specific resistance of Ru which was able to be found experimentally is 30microomegacm, as a shunt effect of  $\sigma$ , it will be made Cu thickness of specific resistance 0microomegacm, and will be called one third of thickness. For example, with composition called Ru1.5 nm/Cu1nm, it will be said with Cu thickness reduced property of a shunt that it is equivalent to  $(1.5nm/3)+1nm=1.5nm$ .

199] Moreover (8-1), as a variation of the example of - (8-4), it is possible to carry out the laminating of the noble-

etals element film further on an antiferromagnetism film. For example, you may use a monolayer or cascade screens, such as Cu, Ru, Pt, Au, Ag, Re, Rh, and Pd. Low  $H_{in}$  is realizable also in the time of thin spacer thickness with this composition. However, if thickness becomes thick not much, since a current diverging ratio will increase in the upper layer side of a free layer, as total thickness of a monolayer or a cascade screen, 0.5nm - about 3nm is desirable.

Example 3) Bottom SFSV (NiFe/Co(Fe) free layer)

a5/Ru2/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu2/Ta5 (9-1)

a5/Ru1/NiFeCr2/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/Co0.5/NiFe2/Cu2/Ta5(9-2)

An antiferromagnetism film shows the so-called bottom type located in a lower layer side rather than a free layer of example. Drawing 6 is a conceptual diagram showing the spin bulb film composition concerning this example. That is, on the ground buffer layer 131, the laminating of the antiferromagnetism film crystal control layer 128 and the antiferromagnetism film 127 was carried out, and the pin layers 126 and 124 have joined together in antiferromagnetism through a layer 125. On the layer 124, the laminating of the spacer layer 123, the free layer 122, and the nonmagnetic quantity conductive layer 121 is carried out one by one, and, finally the cap layer 132 is formed.

[200] The antiferromagnetism film crystal control layer 128 consists of a monolayer Ru, and the antiferromagnetism film of 127 of the example of (9-1) is the case where PtMn and the free layer 122 are formed from the cascade screen of the bilayer of 129 and 130. The antiferromagnetism film crystal control layer 128 is formed from the bilayer film of NiFeCr as Ru and a film of 134 as a film of 133, and the antiferromagnetism film of 127 of the example of (9-2) is an example when IrMn and a free layer are formed from 129 and the two-layer film of 130.

[201] In a bottom type spin bulb film, 1nm - about 5nm of ground films of fcc or hcp is further used as an antiferromagnetism film crystal control layer on buffer layers, such as Ta. For example, Cu, Au, Ru, Pt, Rh, Ag, nickel, NiFe, those alloy films, a cascade screen, etc. are used. These seed (seed) layers are important films in order to raise the function as an antiferromagnetism film. In the example of PtMn of (9-1), the cascade screen of Ru/NiFeCr was used for Ru layer of a monolayer in the example of IrMn of (9-2). Making blocking temperature of an antiferromagnetism film into a sufficiently high value and film flattening are urged to this antiferromagnetism film crystal control layer, and even when the 1.5nm - about 2.5nm ultra-thin spacer needed by this invention is used, it has the work which realizes low  $H_{in}$ .

[202] In respect of the bias point merit by this invention, it is not influenced [ big ] according to the kind of this seed layer in the range of the thickness about [ above-mentioned ] an example. However, it is not desirable to use low electrical resistance materials, i.e., a small material of specific resistance. This is because it will become difficult to bring a current center close to a free layer if a shunt diverging layer increases here. Therefore, it is desirable to use the material of high resistance as much as possible in the range of the material which has a function as an antiferromagnetism film raised. For example, instead of NiFe of low resistance, Cr, Nb, Hf, W, Ta, etc. are added to NiFe, and the example which raises and uses specific resistance can be considered. In (9-2), NiFeCr is used instead of NiFe.

[203] As an antiferromagnetism film, PtMn is used in (9-1) and IrMn is used by (9-2). As a merit using PtMn, that blocking temperature is an elevated temperature,  $H_{u.a.}$ 's being large, and MR heat deterioration after process heat treatment are very small, and it is mentioned that high MR and quantity  $\Delta R_s$  are realizable. When an ultra-thin free layer is used like the time of a top type, the merit using PtMn which is the antiferromagnetism film which contains noble metals from the point that high MR is maintainable after process heat treatment is very large. You may use PdPtMn instead of PtMn. As a desirable thickness range, 5nm - 30nm 7nm - 12nm is good still more preferably.

[204] As a merit using IrMn of (9-2), since a property comes out in a thin film field rather than PtMn, the point of being suitable for the narrow gap head corresponding to densification can be mentioned. As thickness of IrMn, 3nm - 5nm is desirable. Since it is the antiferromagnetism film with which IrMn also contains the noble-metals element Ir, it excels in the thermal resistance of MR rate of change. You may use RuRhMn which contains a noble-metals element similarly instead of IrMn.

[205] As mentioned above, as an antiferromagnetism film, although PtMn, IrMn, and PdPtMn are the most desirable, in respect of the bias point merit of the spin bulb film of this invention, it is not limited by antiferromagnetism film material and the antiferromagnetism film of others of NiO, CrMnPt, NiMn, and  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> grade may be used.

[206] As a ferromagnetic material of the bilayer of a synthetic pin layer, although the CoFe alloy layer was used here, you may use the cascade screen of Co, NiFe or NiFe, and Co or CoFe. Views, such as such components, thickness, etc., are completely the same as that of the top type case of the examples 1 and 2 mentioned above. The composition of this synthetic pin layer that is the important point of this invention is the purpose with biggest reducing a pin disclosure magnetic field as mentioned above, and the  $M_s$  difference of this vertical ferromagnetism layer is closely connected with the thickness of a high conductive layer prepared in contact with a free layer, and is changed.

[207] The time of a top type and a view do not change about a spacer, either, but the thinner possible one is desirable.

pecifically, 1.5nm - about 2.5nm is desirable still more desirable, and 1.8nm - 2.3nm is desirable.

[208] As a free layer, the cascade screen of NiFe/Co is used in the example here. The thickness of this free layer and the view of material are the same as that of the time of a top type almost. However, in the case where the ground films of NiFe are a top type and a bottom type, since it differs, when composition of NiFe for low magnetostriction realization is a top type, it differs a little. Specifically, in the case of a NiFe/CoFe laminating free layer, since it is smaller than the time of the shift by the side of positive [ of the magnetostriction of the NiFe/CoFe laminating free layer accompanying the reduction in the thickness of NiFe ] being a top type, the thing of nickel PUA can also realize the optimal magnetostriction as composition of NiFe rather than the time of a top type.

[209] For example, in the case of a NiFe<sub>3</sub> nm/CoFe<sub>0.5</sub>nm laminating free layer, by the top type, it becomes a still large value to a positive side by nickel<sub>81</sub>Fe<sub>19</sub> (at%) as composition of NiFe, and although it is unusable, by the bottom type, it becomes a positive small magnetostriction value by nickel<sub>81</sub>Fe<sub>19</sub> (at%), and becomes the film which is satisfactory practically.

[210] Cu film is used here as a high conductive layer which is the 2nd of the big points of this invention. This biggest role of a high conductive layer is bringing a current pin center, large close to a free layer as much as possible, and reducing a current magnetic field.

[211] in spite of using the well which also uses the spin-filter effect of MR by Cu conductive layer as still more nearly another effect, and the ultra-thin free layer, there is no degradation of MR rate of change

[212] The range of optimal Cu thickness is the same as that of the time of Top SFSV, and it is the same as that of the time of a top type that an optimum value shifts delicately according to the pin layer membrane thick difference of the upper and lower sides of free thickness and synthetic AF. Moreover, it is in low  $H_{in}$  in an ultra-thin free layer being realizable as another big effects other than bias point adjustment of Cu cap layer, and high MR rate-of-change maintenance. For example, when there is no Cu cap at the same free thickness, and a thing with 30 or more Oe(s) of  $H_{in}$  uses Cu cap, it can decrease up to about 10 Oe(s).

[213] the high conductive layer of the high conductive layer Cu which touched the free layer CoFe as a variation of (9-1) and (9-2) here which becomes replacing from the cascade screen more than a bilayer -- composition -- the bottom also good For example, Cu/Ru, Cu/Re, Cu/Rh, Cu/Pt, etc. are mentioned. since the magnetostriction of a CoFe free layer is influenced by distortion as an effect made into a bilayer as described at the time of a top type, it is the main purposes to adjust magnetostriction  $\lambda$ das Moreover, although it is important in this invention to realize low  $H_{in}$ , it may be made two-layer also for the low  $H_{in}$  control purpose.

[214] The following can be considered as concrete film composition.

[215]

a<sub>5</sub>/Ru/PtMn<sub>10</sub>/CoFe<sub>2</sub>/Ru<sub>0.9</sub>/CoFe<sub>2.5</sub>/Cu<sub>2</sub>/Co<sub>0.5</sub>/NiFe<sub>2</sub>/Cu<sub>1.5</sub>/Ru<sub>1.5</sub>/Ta<sub>5</sub> (9-3)

a<sub>5</sub>/Ru/NiFeCr/IrMn<sub>7</sub>/CoFe<sub>2</sub>/Ru<sub>0.9</sub>/CoFe<sub>2.5</sub>/Cu<sub>2</sub>/Co<sub>0.5</sub>/NiFe<sub>2</sub>/Cu<sub>1.5</sub>/Ru<sub>1.5</sub>/Ta<sub>5</sub>(9-4)

at the above-mentioned film composition, to specific resistance 10microomegacm of Cu thin film, since Ru is 0.5microomegacm, as an electric shunt effect, Ru<sub>3</sub>nm will bring about an equivalent effect to Cu<sub>1</sub>nm. That is, in the above (9-3) and the film of (9-4), the thickness of a high conductive layer will say that it is equivalent to 2nm by Cu conversion. Since it is used in the range to 0.5nm - 3nm in the case of Cu monolayer, Ru is similarly used in 0.5nm - 3nm. However, as a high conductive layer which touches CoFe, since it is not desirable from the point of a narrow gap to make Ru not much thick, after using 0.5nm - about 2nm of Cu thickness using Cu etc. by carrying out in contact with CoFe, it is desirable [ the Cu is more desirable, and ], since [ that specific resistance is also high in Ru ] the spin-filter effect is weaker than the case of Cu to use other two-layer metallic materials.

Example 4) Bottom SFSV (CoFe free layer)

a<sub>5</sub>/Ru<sub>2</sub>/PtMn<sub>10</sub>/CoFe<sub>2</sub>/Ru<sub>0.9</sub>/CoFe<sub>2.5</sub>/Cu<sub>2</sub>/CoFe<sub>2</sub>/Cu<sub>2</sub>/Ta<sub>5</sub> (10-1)

a<sub>5</sub>/Ru<sub>1</sub>/NiFeCr/IrMn<sub>7</sub>/CoFe<sub>2</sub>/Ru<sub>0.9</sub>/CoFe<sub>2.5</sub>/Cu<sub>2</sub>/CoFe<sub>2</sub>/Cu<sub>2</sub>/Ta<sub>5</sub> (10-2) this example It is the thing of the type with which it belongs to the bottom type illustrated to drawing 2 , and the CoFe layer of a monolayer is used instead of the free layer 122. Except it, it is the same as that of the example 3 mentioned above. The material of layers other than free layer and the view of thickness are completely the same as that of an example 3. The merit using a CoFe free layer is the same as that of the time of a top type. In this example,  $M_s \cdot t$  by NiFe conversion at the time of 3.6nmT(s) furthermore, but As opposed to the spin-filter effect being thinly acquired by 2.5nm of thickness, if it is a CoFe monolayer free layer when  $M_s \cdot t$ -4.5nmT compares If it is NiFe/Co (Fe), NiFe<sub>4</sub>/Co<sub>0.5</sub> (nm) and the total thickness will become thick, and the spin-filter effect of MR by preparing a high conductive layer is not acquired. A simple shunt layer and a bird clapper, And the shunt effect of the NiFe itself also decreases 0 to 30% by  $\Delta R_s$  from a certain thing compared with a CoFe monolayer free layer.

[216] this example which is an example of a CoFe free layer also from the spin-filter effect of  $M_s \cdot t$  being acquired from the above thing in the latus range of  $M_s \cdot t$  is more desirable than the case of an example 3.

10-1) and (10-2) here which becomes replacing from the cascade screen more than a bilayer -- composition -- the bottom is also good For example, Cu/Ru, Cu/Re, Cu/Rh, etc. are mentioned. since the magnetostriction of a CoFe free layer is influenced by distortion like previous statement as an effect made into a bilayer, it is the main purposes to adjust magnetostriction  $\lambda$  Morevoer, although it is important in this invention to realize low  $H_{in}$ , it may be made mono-layer also for the low  $H_{in}$  control purpose. The following can be considered as concrete film composition.

a5/NiFe/PtMn10/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu1.5/Ru1.5/Ta5(10-3)

a5/NiFe/IrMn7/CoFe2/Ru0.9/CoFe2.5/Cu2/CoFe2/Cu1.5/Ru1.5/Ta5 (10-4)

here is also magnetostriction control by changing composition of CoFe in addition to the method of controlling the magnetostriction of CoFe by the above cascade-screen nonmagnetic quantity conductive layers. Although the way of a round film generally tends to do the distorted adjustment which joins a free layer, it is because it becomes difficult to choose the material in the free layer bottom freely by the bottom type. If the laminating of the CoFe will be carried out on Cu at the time of a bottom type and Co90Fe10 (at%) is then used, it will be easy to become the big magnetostriction of a negative side. in order to shift it to a positive side -- Co -- it is desirable to use rich CoFe Specifically, it is Co90Fe10-. It is desirable to use the CoFe free layer of Co96Fe4 (at%). however, Co -- if it is made rich and a hcp phase is intermingled, since the soft magnetism of a free layer will deteriorate ( $H_c$  increases), it is not desirable to use a CoFe alloy like Co98Fe2 over which it passes richly [ Co ]

10-18] In the above-mentioned film composition, to specific resistance 10microomegacm of Cu thin film, since Ru is 0microomegacm, as an electric shunt effect, Ru3nm will bring about an equivalent effect to Cu1nm. That is, in the above (10-3) and the film of (10-4), the thickness of a high conductive layer will say that it is equivalent to 2nm by Cu conversion. Since it is used in the range to 0.5nm - 3nm in the case of Cu monolayer, Ru is similarly used in 0.5nm - 3nm. However, as a high conductive layer which touches CoFe, since it is not desirable from the point of a narrow gap to make Ru not much thick, after using 0.5nm - about 1nm of Cu thickness using Cu etc. by carrying out in contact with CoFe, it is desirable [ the Cu is more desirable, and ], since [ that specific resistance is also high in Ru ] the spin-orbit effect is weaker than the case of Cu to use other two-layer metallic materials.

The 2- gestalt : improvement in high temperature oxidation stability and a reproduction output of the 6th operation) Next, the gestalt of the 2nd - the 6th operation of this invention seen from a viewpoint of improvement in high temperature oxidation stability and a reproduction output is explained.

10-19] First, it outlines about technical thought common to the gestalt of the 2nd - the 6th operation.

10-20] Drawing 17 is drawing showing the gestalt of the 1 operation of the gestalten of the 2nd - the 6th operation of this invention. In drawing 17 , the lower shield 11 and the lower gap film 12 are formed in a substrate 10, and the spin bulb element 13 is formed on it. A spin bulb element consists of a spin bulb film 14, a vertical bias film 15 of a couple, and an electrode 16 of a couple, and the nonmagnetic ground layers 141 and 142, the antiferromagnetism layer 143, the magnetization fixing layer 144, the interlayer 145, the magnetization free layer 146, and the protective coat 147 are formed further.

10-21] Resistance rate-of-change  $\Delta R/R$  of the material composition and thickness of an antiferromagnetism layer which are combined with the ferromagnetic layer of SyAF at the time of using SyAF of the gestalt of operation of this invention for a magnetization fixing layer, the switched connection constant J in 200 degrees C and exchange bias magnetic field  $H_{UA}^*$  and  $H_{UA}$ , the blocking temperature  $T_b$ , and a spin bulb element is shown in Table 6. Moreover, the same table at the time of using the magnetization fixing layer of the conventional monolayer as a magnetization fixing layer is shown in Table 7. Moreover, the relation between the switched connection constant J of rocking curve half-value-width  $\Delta\theta$  of the diffraction line peak from the maximum \*\*\*\* of the antiferromagnetism layer combined with SyAF and the antiferromagnetism layer side ferromagnetism layer of SyAF in 200 degrees C and the blocking temperature  $T_b$  is shown in Table 8.

10-22]

Table 1]

8

ピンバルブ膜構成:

基板/Ta (5nm) /NiFe/CoFe/Cu (3nm) /CoFe (2.5nm)  
 /Ru (0.9nm) /CoFe (2.5nm) /反強磁性層/Ta (5nm)

反強磁性層 材料	膜厚(nm)	200℃における J (erg/cm <sup>2</sup> )	200℃における H <sub>ex</sub> * (Oe)	ブロッキング 温度T <sub>b</sub> (℃)	抵抗変化率 ΔR/R (%)
Ir <sub>22</sub> Mn <sub>78</sub>  (比較例)	5	0.04	400	250	7.3
	7	0.045	450	270	7.3
	10	0.045	450	290	7
	20	0.04	400	300	6.5
	30	0.035	350	300	5.5
Rh <sub>20</sub> Mn <sub>80</sub>	7	0.025	250	235	7.1
	10	0.035	350	260	6.8
Rh <sub>14</sub> Ru <sub>7</sub> Mn <sub>79</sub>	7	0.02	200	225	7.2
	10	0.03	300	245	6.8
Pt <sub>83</sub> Mn <sub>17</sub>  (比較例)	10	0.02	250	290	7.9
	15	0.025	400	320	7.4
	20	0.1	>600	350	7
	30	0.12	>600	370	6.2
Ir <sub>50</sub> Mn <sub>50</sub>	15	0.02	250	300	6.8
IrMnPt	15	0.02	200	240	6.9

IrMn, RhMn, RhRuMn, CrMnPtを用いたスピンバルブ膜:

270℃, 1時間の熱処理を施した後の結果

PtMn, NiMnを用いたスピンバルブ膜:

270℃, 10時間の熱処理を施した後の結果

[223]

Table 2]

7

ピンバルブ膜構成:

基板/Ta (5nm) /NiFe/CoFe/Cu (3nm) /CoFe (2.5nm)  
 /反強磁性層/Ta (5nm)

反強磁性層 材料	膜厚(nm)	200℃における J (erg/cm <sup>2</sup> )	200℃における H <sub>ex</sub> (Oe)	ブロッキング 温度T <sub>b</sub> (℃)	抵抗変化率 ΔR/R (%)
Ir <sub>22</sub> Mn <sub>78</sub>	5	0.04	170	250	6.6
	10	0.045	190	290	6.2
Pt <sub>61</sub> Mn <sub>39</sub>	10	0.03	130	300	7.2
	20	0.1	430	350	6.7
	30	0.12	510	370	6.4

IrMnを用いたスピンバルブ膜: 270℃, 1時間の熱処理を施した後の結果

PtMnを用いたスピンバルブ膜: 270℃, 10時間の熱処理を施した後の結果

[224]

Table 3]

反強磁性層 材料	膜厚 (nm)	最密面ピークのロッキング カーブ半値幅 $\Delta \theta$ (°)	200℃における J (erg/cm <sup>2</sup> )	ロッキング 温度 T <sub>b</sub> (℃)
r 22Mn78	5	12	0.01	210
	5	8	0.025	230
	5	5	0.045	250
	5	3	0.05	250
b 20Mn80	7	13.5	~0	190
	7	8	0.02	225
	7	4	0.025	235

s invention person constitutes the magnetization fixing layer combined with 1 antiferromagnetism layer by SyAF, as shown in Table 6 and 8. They are 0.02 erg/cm<sup>2</sup> as a switched connection constant J in the temperature of 200 degrees if composition of an antiferromagnetism layer is chosen. The above can be obtained, 2) when carrying out orientation of the maximum \*\*\*\* so that the rocking curve half-value width of the maximum \*\*\*\* peak of an antiferromagnetism layer may become small, and making it 8 degrees or less of rocking curve half-value width become degrees or less still more preferably. That the switched connection constant J in the temperature of 200 degrees C can be raised, and by setting more preferably 20nm or less of magnetic thickness of 3 antiferromagnetism layers to 10nm or less. It is the switched connection constant J in that it can raise more than equivalent with the resistance rate of change of the spin bulb element which constituted resistance rate of change using the magnetization fixing layer of a monolayer, and 4 temperature of 200 degrees C 0.02 erg/cm<sup>2</sup>. By carrying out above. It sets in temperature of 200 degrees C, and is exchange bias magnetic field HUA\*. It could be made 200 or more Oes, and even the maximum magnetic fields which join the spin bulb element of a reproduction element from a record medium etc. are 200Oe(s), it finds out that a stable magnetization fixing layer is obtained, and came to make this invention.

225] Drawing 18 is [ the change of the resistance of a spin bulb film to an external magnetic field, and ] exchange bias magnetic field HUA\*. It is shown \*\* type view. It is exchange bias magnetic field HUA\* at drawing 18. It is defined as the value of the magnetic field which calculated the maximum of the magnetic field by which magnetization of a magnetization fixing layer does not move substantially as an intersection of the extension wire of the bay by the side of a low magnetic field, and the extension wire of the bay of a high magnetic field. exchange bias magnetic field HUA\* \*\*\*\*\* -- in resistance-magnetic influence when the magnetization fixing layer which has 200 or more Oes holds an external magnetic field in the magnetization fixing direction, resistance change magnetization hardly moved in the magnetic field range to 200Oe, and only the magnetization free layer carried out [ change ] the magnetization response is obtained.

226] After the magnetic field which is the operating point as a magnetic field sensor is accepted near the zero on the curve only the steep resistance change accompanying the magnetization response of a magnetization free layer indicates resistance-magnetic influence to be, and change of resistance is not accepted to the external magnetic field to 200Oe other than the magnetization response of this magnetization free layer but a magnetization free layer is saturated with drawing 18, it is shown that there is no substantial response to a magnetic field.

227] When a conventional NiO antiferromagnetism layer and a conventional FeMnCr antiferromagnetism layer are used, in 200 degrees C, J is hardly obtained. Moreover, since resistance rate of change becomes lower than the magnetization fixing layer of the conventional monolayer when the CrMnPt antiferromagnetism layer of 30nm \*\* is used, it is not desirable.

228] In the magnetization fixing layer of the conventional monolayer, although high HUA is obtained by 20nm thick or less when PtMn is used as shown in Table 7, the resistance rate of change in that case indicates a low value comparatively to be 6.4 - 6.7%.

229] On the other hand, it is HUA\* at 200 degrees C by using an antiferromagnetism layer with a thickness [ , such as Mn, RhMn, RhRuMn, PtMn, NiMn, and CrMnPt, ] of 20nm or less according to the gestalt of operation of this invention shown in Table 6. The outstanding thermal resistance of 200 or more Oes is satisfied, and, moreover, resistance rate of change's being equivalent to the case the magnetization fixing layer of the conventional monolayer being used, or the value beyond it is acquired. In addition, in this invention, the minimum of antiferromagnetism layer thickness is 3nm or more preferably.

230] Drawing 19 is HUA\*. The relation between elapsed time when the spin bulb film of the operation gestalt of this invention of 200Oe(s) and the conventional HUA give the simulation bias magnetic field of 200Oe(s) at 200 degrees C

out the spin bulb film of the monolayer magnetization fixing layer of 500Oe(s), and the angle by which magnetization of a magnetization fixing layer moved is shown. The spin bulb film of the operation gestalt of this invention is HUA\* in 200 degrees C [ as shown in drawing 19 / the spin bulb film of the conventional monolayer magnetization fixing layer ]. In spite of being small compared with 200Oe(s), and HUA of a monolayer magnetization fixing layer and 510Oe, it turns out that aging of the fixing magnetization in 200 degrees C is slight, and it excels in ability.

231] moreover, Mn, such as IrMn, RhMn, and RhRuMn, -- in antiferromagnetism thickness 10nm or less, large distance rate of change is obtained and it is still more desirable than the case where the magnetization fixing layer of the conventional monolayer is used so that it may see, when a rich gamma-Mn system antiferromagnetic substance is used

232] Moreover, in the form of operation of this invention of Table 6, the antiferromagnetism layer of the range of Tb is 240-300 degrees C shows the thermal resistance of good fixing magnetization. Therefore, since the magnetization direction of a magnetization fixing layer is freely controllable by the external magnetic field by adding the big magnetic field exceeding the joint magnetic field of a magnetic coupling layer near the Tb, and saturating the ferromagnetic layer A and the ferromagnetic layer B in this direction, the magnetization fixing processing of diffusion between a magnetic coupling layer, and the ferromagnetic layer A and the ferromagnetic layer B at 300 degrees C or less which seldom poses a problem is attained.

233] In order to prevent the influence of diffusion between a magnetic coupling layer, and the ferromagnetic layer A and the ferromagnetic layer B, or diffusion, it is desirable that thickness exceeds 0.8nm as a magnetic coupling layer, and it is desirable to use Ru, Rh, Cr, Ir, etc. Moreover, it is effective in the ferromagnetic layer A and the ferromagnetic layer B to use Co alloys, such as CoFe, and equivalent [ to the thickness of a magnetic coupling layer ] or to hold down the irregularity of a magnetic coupling layer to less than [ it ].

234] furthermore, in the magnetization direction convention heat treatment of a magnetization fixing layer Since it is necessary to saturate the ferromagnetic layer A and the ferromagnetic layer B in this direction, if the thickness of the ferromagnetic layer A and the ferromagnetic layer B becomes thin to about 2nm When magnetic coupling thickness is 8nm or less, the antiferromagnetism-joint magnetic field of a magnetic coupling layer will increase more than about 7 Oe(s) or it, and the magnetization direction convention heat treatment of a magnetization fixing layer will become difficult by the practical external magnetic field. For this reason, the magnetization direction convention heat treatment of a magnetization fixing layer is possible for magnetic coupling thickness, and it is desirable at an external magnetic field with more practical making it the thickness exceeding 0.8nm, for example, 7kOe(s).

235] In the SyAF magnetic coupling layer adopted in the form of operation of this invention of Table 6, by considering as the thickness of 0.9nm of the magnetic coupling layer by which the thickness of the ferromagnetic layer which consisted of CoFe alloys, and the ferromagnetic layer B was constituted from 2.5nm and Ru, antiferromagnetism joint magnetic fields are about 4 kOe(s), and can perform heat-resistant reservation of a magnetization fixing layer good enough by the antiferromagnetism magnetic field of this level.

236] In this invention, the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, or composition with the magnetic thickness of the ferromagnetic layer A thicker than the magnetic thickness of the ferromagnetic layer B is desirable. When the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, compared with the case where the magnetic thickness of the ferromagnetic layer A is thicker than the magnetic thickness of the ferromagnetic layer B, magnetization of a magnetization fixing layer is remarkably stable to a medium magnetic field or a vertical bias magnetic field.

237] On the other hand, when the magnetic thickness of the ferromagnetic layer A is larger than the magnetic thickness of the ferromagnetic layer B, compared with the case where the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, a good ESD property without the fixing flux reversal by ESD can be realized. In this case, it is desirable that the ratio of the magnetic thickness of the ferromagnetic layer B to the magnetic thickness of the ferromagnetic layer A considers as the range of 0.7-0.9. For example, it is desirable to consider [ the ferromagnetic layer A ] as a 2nm CoFe alloy at a 2.5nm CoFe alloy and the ferromagnetic layer B. Even when the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is almost equal, even if the fixing flux reversal by ESD arises by what the circuit which re-fixes magnetization of a magnetization fixing layer in the predetermined direction by current is included in a magnetic disk drive for (for example, U.S. Pat. No. 5650887), the drive which can re-fix can be realized. The values of J in 200 degrees C are 0.02 erg/cm<sup>2</sup>. In order to realize the above The gamma-Mn phase which consists of IrMn, RhMn, RhRuMn, etc. which make Mn a principal component, Or the antiferromagnetism layer (it is easy to realize composition of Mn at less than 40% exceeding 0) which makes the rule-ized phase of an AuCuII form the main phase Or it is desirable to use the antiferromagnetism layer (for it to be easy to realize Mn composition at 70% or less 40% or more) containing the rule-ized phase (CuAul type) of the face-

ntered tetragon which consists of PtMn, PtPdMn, NiMn, etc., or Cr system antiferromagnetism layers, such as CrMn and CrAl.

238] The values of  $J$  [ in / 200 degrees C / furthermore / with these alloys ] are 0.02 erg/cm<sup>2</sup>. In order to realize the above in the thin antiferromagnetism layer from which high resistance rate of change is obtained, it is required to realize the crystal structure in which the maximum \*\*\*\* carried out orientation.

239] For rocking curve half-value-width  $\Delta\theta$  of the diffraction line peak from the maximum \*\*\*\* and half-value-width [ from the relation between  $T_b$  and  $J$  ]  $\Delta\theta$  showing the amount of preferred orientation shown in Table 8 which are a parameter, the values of  $J$  are 0.02 erg/cm<sup>2</sup> at 8 degrees or less. It turns out that the above is attained and the magnetoresistance-effect head of this invention can be realized. If the maximum \*\*\*\* carries out orientation to face-centered tetragons, such as PtMn, similarly in the rule-ized antiferromagnetism layer of bcc systems, such as an antiferromagnetism layer and CrMn,  $J$  high  $T_b$  in thin antiferromagnetism thickness and high at 10 degrees C is realizable. here -- the maximum \*\*\*\* -- in the case of a fcc phase, in the case of a hcp phase, a peak (02) is meant, and, as for the case of a bcc phase, a peak (110) is meant for a peak (111), respectively Moreover, in Mn containing the rule-ized phase which consists of a face-centered tetragon etc., it means that the fcc phase which mainly is carrying out plane orientation (111), or that the rule-ized field (111) of a face-centered tetragon is carrying out orientation. In addition, in the case of a fcc phase or a hcp phase, a stacking fault may also be included.

240] In addition, as shown in drawing 20, the fluctuation from the film surface perpendicular direction of the maximum \*\*\*\* spot in the transmission-electron-microscope diffraction image from a head cross section can also express the rocking curve half-value width of the diffraction line peak from the maximum \*\*\*\*, and the rocking curve half-value width and the fluctuation angle of the maximum \*\*\*\* spot of a transmission-electron-microscope diffraction image by X-ray diffraction are in agreement in general.

241] In order to realize such a good maximum \*\*\*\* array, membrane formation of a spin bulb film is performed in the atmosphere which suppressed impurities, such as oxygen gas, as much as possible. For example, the membrane formation by the equipment by which preliminary exhaust air is made even on a 10<sup>-9</sup>Torr base, 500 ppm Membrane formation using the sputter target which suppressed the oxygen content below, The membrane formation given in case sputter atom deposits moderate energy on a substrate by methods, such as a substrate bias sputter There are methods, such as preparing nickel system alloy layers, such as a noble-metals simple substance or alloy ground layers, such as a ground layer, for example, Au, Cu, Ag, Ru, Rh, Ir, Pt, Pd, etc., and NiFe, NiCu, NiFeCr, NiFeTa, between an alumina layer and a spin bulb film.

242] As mentioned above, it outlined about the technical thought [-like in common ] about the gestalt of the 2nd of this invention about "improvement in thermal resistance and a reproduction output" - the 6th operation.

243] Next, the gestalt of the 2nd - the 6th operation of this invention is explained in detail.

244] (Gestalt 2 of operation) An example of the magnetoresistance-effect head which starts this operation gestalt at drawing 17 is shown. In drawing 17, the lower shield 11 and the lower gap film 12 are formed in the Al (Chick aluminum 2O<sub>3</sub> and TiC) substrate 10, and the spin bulb element 13 is formed on it. The lower shields 11 are NiFe which has the thickness of 0.5-3 micrometers, Co system amorphous magnetism alloy, a FeAlSi alloy, etc., and it is desirable to remove surface irregularity by polish with NiFe or a FeAlSi alloy here. Moreover, an alumina with a thickness of 5-100nm, nitriding aluminum, etc. are used for the lower gap film 12.

245] A spin bulb element consists of a spin bulb film 14, a vertical bias film 15 of a couple, and an electrode 16 of a couple. A spin bulb film consists of protective coats 147 with a thickness of 0.5-10nm the 2nd ground layer 142 with a thickness of 0.5-5nm, the antiferromagnetism layer 143, the magnetization fixing layer 144, the interlayer 145 with a thickness of 0.5-4nm, the magnetization free layer 146, and if needed the nonmagnetic ground layer 141 with a thickness [ , such as Ta, Nb, Zr, and Hf, ] of 1-10nm and if needed.

246] The gap layer 17 and the upper shield 18 are formed on it. Moreover, although not illustrated, the Records department is further formed on it. As for the gap layer 17, NiFe which is used and has the thickness of 0.5-3 micrometers to the upper shield 18, Co system amorphous [ an alumina with a thickness of 5-100nm, nitriding aluminum, etc. ] magnetism alloy, a FeAlSi alloy, etc. are used.

247] When the rule system alloy of face-centered tetragons, such as Mn rich alloy of gamma-Mn systems, such as Mn, RhMn, and RhRuMn, and PtMn, NiMn, is used as an antiferromagnetism layer 143 AuCu to which the ground layer 142 makes a principal component them, such as Cu, Ag, Pt, Au, Rh, Ir, and nickel The hcp phase metal which consists of alloys [ , such as Ru and Ti, ] which make them a principal component, such as alloys, such as CuCr, nickel of a Japanese Patent Application No. [ No. 229736 / nine to ] publication, nickel system alloy, NiFe, and a NiFe system alloy, is desirable.

248] Moreover, although the ground layer mentioned above is sufficient as the ground layer 142 when using Cr system antiferromagnetism alloy film as an antiferromagnetism layer 143, the ground layer which consists of alloys

hich make them a principal component, such as Cr, V, Fe, etc. which consist of a bcc layer, is also suitable.

[249] The magnetization fixing layer 144 consists of three layer membranes which consist of 1443 of 1441 of the ferro-layer ferromagnetic layer B combined in antiferromagnetism through the magnetic coupling layer 1442, and the ferromagnetic layer A. Since a big resistance change will be obtained if nonmetals, such as oxygen and nitrogen, are inserted in the middle of the ferromagnetic layer B and the antiferromagnetism layer 143, or the middle of the ferromagnetic layer B and the antiferromagnetism film of a vertical bias film, it is desirable. In this case, the layer thickness which inserts a nonmetal has desirable 0.2-2nm. For example, ferromagnetic layer A (or the ferromagnetic layer B) / oxidizing zone / ferromagnetic layer B (or the ferromagnetic layer A) which minded the oxidizing zone in the middle for the ferromagnetic layer A (or the ferromagnetic layer B) are desirable.

[250] The magnetic coupling layer 1442 has desirable Cr from which an antiferromagnetism joint function is obtained. The metal which consists of Ru, Rh, Ir, and Cr, Ru which has a big antiferromagnetism joint function especially, Ru which has an antiferromagnetism joint function in the latus thickness range, or the latus thickness range. It is usable if is the thickness which can discover an antiferromagnetism joint function as shown in reference (Phy.Rev.Lett.67. 991) 3598) as thickness of a magnetic coupling layer.

[251] Residual magnetization ratio  $M_r/M_s$  shows Ru \*\* after heat treatment at the time of using Ru for the magnetic coupling layer of the ferromagnetic layer of Co, and the ferromagnetic layer of a CoFe alloy, and the relation of the fall degree of antiferromagnetism combination to drawing 21.  $M_r/M_s=1$  shows that antiferromagnetism combination is completely disappearance and antiferromagnetism combination with perfect  $M_r/M_s=0$  here.

[252] 1.2nm or less is desirable exceeding 0.8nm which does not produce property degradation of the magnetic coupling function by counter diffusion with the ferromagnetic layer B, and the ferromagnetic layer A and the magnetic coupling layer which adjoins even if it performs heat treatment at 250-300 degrees C which is needed at the head process of heat treatment or others of deciding the magnetization direction of the magnetization fixing layer 144 depending on the case when Ru is used for a magnetic coupling layer as shown in drawing 21 etc. Antiferromagnetism combination will become difficult, if Ru layer needs to pay attention for the fall of the antiferromagnetism joint function by counter diffusion in 0.8nm or less and exceeds 1.2nm \*\* on the other hand. Moreover, when Cr is used for magnetic coupling layer, 1.5nm or less is desirable at the same reason as the case where Ru is used, exceeding 0.8nm. And in the ferromagnetic layer B and the ferromagnetic layer A, Co or Co system alloy is desirable.

[253] If a  $\text{Co}_{1-x}\text{Fe}$  alloy ( $0 < x \leq 0.5$ ) is used for the ferromagnetic layer B and the ferromagnetic layer A, especially once a big switched connection coefficient with the antiferromagnetism layer 143 which consists of a Mn rich alloy of gamma-Mn systems, such as IrMn, RhMn, and RhRuMn, is obtained and diffusion with Ru, the ferromagnetic layer B, and the ferromagnetic layer A can moreover be prevented, it is desirable. In replacing with a CoFe alloy and using Co, compared with the case where 270 degrees C and the thickness range of the magnetic coupling layer which can maintain a stable magnetic coupling function also with heat treatment about maintenance for 1 hour are CoFe alloys as is about set to two thirds and it is shown in drawing 21, it becomes narrow.

[254] In addition, the surface smooth nature of a magnetic coupling layer is also important in order to maintain the thermal resistance of the antiferromagnetism joint function, and it is 2 10nm. Generating of the bigger surface regularity in the minute field in the film surface of a grade than the thickness of a magnetic coupling layer degrades the thermal resistance of an antiferromagnetism joint function. Therefore, as for the size of the surface irregularity of a magnetic coupling layer, it is desirable that it is below the thickness of a magnetic coupling layer.

[255] Change of the spin bulb film surface resistance  $R_s$  to the thickness of the ferromagnetic layer A and the ferromagnetic layer B, field resistance change  $\Delta R_s$ , and resistance rate-of-change  $\Delta R/R$  is shown in Table 9. Moreover, the change of resistance to the magnetic field of a spin bulb film is shown in drawing 22.

[256]

[table 4]

図9

スピナル膜の構成:

Ta/Au/CuMn/強磁性層A (CoFe)/Ru (0.9nm)

/強磁性層B (CoFe)/Cu (2.5nm)/磁化自由層

(CoFe 4nm)/Ta

処理: 270℃、1時間

強磁性層A 厚さ (nm)	強磁性層B 厚さ (nm)	抵抗変化率 $\Delta R/R$ (%)	表面抵抗値 $R_s$ ( $\Omega$ )	表面抵抗変化量 $\Delta R_s$ ( $\Omega$ )
7	7	7.2	7.5	0.54
5	5	8.0	9.8	0.78
3	3	8.6	12	1.03
2	2	8.4	14.1	1.18
1	1	8.0	15.3	1.22
0.5	0.5	5.9	15.6	0.92

ie external magnetic field with which the thickness of the ferromagnetic layer B and the ferromagnetic layer A was desirable in order to obtain resistance rate of change with big 1-5nm, and 1nm - 3nm thickness was especially indicated to be to drawing 22 from Table 9 -- receiving -- a stable (the falls of resistance are few even if it adds the external magnetic field of +600Oe) magnetization fixing layer -- in addition, especially since the strong spin bulb film surface resistance  $R_s$  is obtained and field resistance change  $\Delta R_s$  can also be satisfied, it is desirable Here, only by being large, since a reproduction output is proportional to the product of sense current and resistance change and resistance change is proportional to the product of field resistance of resistance rate of change and a spin bulb film, resistance rate of change cannot obtain high power, when field resistance is small. That is, in order to obtain high power, high field resistance is required with high resistance rate of change.

257] Drawing 23 is drawing showing the resistance change by the magnetic field at the time of setting thickness of the ferromagnetic layer A constant 3nm, and changing the thickness of the ferromagnetic layer B.

258] If magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is made equal so that drawing 3 may see, change of resistance by the high magnetic field of +600Oe is small, therefore a remarkable stable magnetization fixing layer can be realized to a medium magnetic field, the magnetic field from a vertical bias layer, the external magnetic field at the time of the Records Department formation heat treatment, etc. Moreover, the problem of the flux reversal of the magnetization fixing layer by ESD is current by the circuit which compensates the fixing magnetization direction included in the drive, as already stated, and it can respond by returning the magnetization direction towards desired.

259] On the other hand, the following advantages are acquired by changing the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B. Operation of magnetization fixing by heat treatment for making the 1st and magnetization of the magnetization free layer which is the fundamental composition of a spin bulb, and a magnetization fixing layer cross at right angles first becomes easy. Higher resistance rate of change is obtained by making magnetic thickness of the ferromagnetic layer B smaller than the magnetic thickness of the ferromagnetic layer A, by the table 10 showing the relation between the thickness of the ferromagnetic layer B, and resistance rate of change in the 2nd, so that clearly. The flux reversal of the magnetization fixing layer by ESD will hardly happen 3rd ], and a stable reproduction output is obtained to near the breakdown voltage. It is the voltage on which a spin bulb element destroys breakdown voltage with voltage here, and spin bulb element resistance begins to increase.

260]

Table 5]

図10

スピナル膜の構成:

Ta (5nm)/AuCu (2nm)/CoFe (5nm)/Cu (3nm)

/強磁性層A (CoFe)/Ru (0.9nm)/強磁性層B (CoFe)

/IrMn (10nm)/Ta (5nm)

強磁性層A 厚さ (nm)	強磁性層B 厚さ (nm)	抵抗変化率 $\Delta R/R$ (%)
3	3	7.3
3	2.5	7.8
3	2	7.7

For example, when the ratio of the magnetic thickness of the ferromagnetic layer B and the ferromagnetic layer A is set to the ferromagnetic layer A, the ferromagnetic layer B, and a magnetization free layer 0.7-0.9 when Co, CoFe, and NiFe are used, respectively and Cu is used for a nonmagnetic interlayer, and the thickness of the ferromagnetic layer B is set as 2.5nm, a good ESD property as shown in [drawing 24](#), [drawing 25](#), and Table 11 can be acquired. Resistance and an output after [drawing 24](#) and [drawing 25](#) give the ESD voltage of the simulation by the human body model to a spin bulb element here are shown, and [drawing 24](#) shows the case where the magnetic thickness of [drawing 25](#) of the ferromagnetic layer A is larger than the magnetic thickness of the ferromagnetic layer B, when the magnetic thickness of the ferromagnetic layer A and the ferromagnetic layer B is equal. Moreover, Table 11 shows the ESD property by the test pattern to a spin bulb element.

[261]

Table 6]

11

ピンバルブ構成:

Ta (5nm) / 磁化自由層 / Cu (3nm) / 強磁性層A / Ru (0.9nm)

/ 強磁性層B / IrMn (10nm) / Ta (5nm)

子構成: パターンニング無しの下シールド、下キャップ上に形成したCoPt / FeCo

下地ハード膜縦バイアスおよびおよび電極が縦バイアス間隔よりも狭いリードオーバーレイを用いた構造 (シールドは無し)。

電極間隔=1.3μm

磁気膜厚比 $(Ms \cdot t) A / (Ms \cdot t) B$	強磁性層A	強磁性層B	磁化自由層	固定磁化 反転電圧	ブレーク ダウン電圧
0.75	CoFe(2nm)	CoFe(1.5nm)	CoFe(3nm)/NiFe(1.5nm)	反転せず	70V
0.8	CoFe(2.5nm)	CoFe(2nm)	CoFe(3nm)/NiFe(1.5nm)	反転せず	75V
0.83	CoFe(3nm)	CoFe(2.5nm)	CoFe(4nm)/NiFe(1.8nm)	反転せず	70V
0.85	Co(2nm)	Co(1.7nm)	Co(0.5nm)/NiFe(4nm)	反転せず	70V
0.71	CoFe(2.4nm)	CoFe(1.7nm)	CoFe(1nm)/NiFe(3nm)	65V	75V
0.88	CoFe(2.4nm)	CoFe(2.1nm)	CoFe(1nm)/NiFe(3nm)	65V	75V
1	CoFe(3nm)	CoFe(3nm)	CoFe(4nm)/NiFe(1.8nm)	50V	75V
0.667	CoFe(3nm)	CoFe(2nm)	CoFe(3nm)/NiFe(1.5nm)	55V	75V
0.93	CoFe(3nm)	CoFe(2.8nm)	CoFe(1nm)/NiFe(3nm)	55V	70V

Although the magnetic field which is mainly concerned with a current magnetic field in a magnetization fixing layer at the time of ESD generating is strongly added [ rather than ] to the ferromagnetic layer A to the ferromagnetic layer B, this is The ratio of the current magnetic field, and  $H(\text{current}) B / H(\text{current}) A$  Since it is mostly in agreement with the reciprocal ratio of magnetic thickness, and  $A (Ms \cdot t) / (Ms \cdot t) B$  The variation of the energy of the magnetization and external magnetic field of the ferromagnetic layer A and the ferromagnetic layer B offsets each other. It is because the energy change as the whole and  $\{(Ms \cdot t) - H(\text{current})\} A - \{(Ms \cdot t) H(\text{current})\} B$  can realize a small state and, as a result, cannot move magnetization of a magnetization fixing layer by the ESD current magnetic field.

[262] When the ferromagnetic layer A is 2nm as shown in [drawing 23](#), therefore  $(Ms \cdot t) 3nm$  and the ferromagnetic layer B are set to  $B / (Ms \cdot t) A = 0.67$ , they compare the ferromagnetic layer A and the ferromagnetic layer B with the case of this 3nm drawing (a), and it is HUA\*. It falls, therefore the thermal resistance of a magnetization fixing layer also falls. Thus, when magnetic thickness of the ferromagnetic layer B is made smaller than the ferromagnetic layer A, it is desirable to choose the energization direction of sense current so that the magnetic field from sense current may be added in the same direction (namely, the same direction as magnetization of the ferromagnetic layer B) as the bias magnetic field from the antiferromagnetism layer which joins the ferromagnetic layer B. Since the disclosure magnetic field by which it is equivalent to the magnetic thickness difference of the ferromagnetic layer A and the ferromagnetic layer B like the spin bulb film of the magnetization fixing layer of the conventional monolayer when the direction of the ferromagnetic layer A has magnetic large thickness joins a magnetization free layer, the reason Although magnetization rectangular cross arrangement with a magnetization free layer and a magnetization fixing layer is disturbed and the fall of a reproduction output produces the problem of the vertical asymmetry of a reproduction wave increasing This disclosure magnetic field can be offset by passing sense current so that the magnetic field by sense current may be added in an exchange bias magnetic field and this direction, as shown in [drawing 26](#) which shows the magnetization and disclosure magnetic field in a spin bulb.

[263] It is desirable to use for a nonmagnetic interlayer the alloy which makes a principal component Cu, Au, Ag, or any simple substance, or them. Although it can be fundamentally used if it is about 1-10nm which is the range which can

tain resistance rate of change, especially since the ferromagnetic-like joint magnetic field which the thickness range 1.5nm - 2.5nm generates between a magnetization fixing layer and a magnetization free layer can be suppressed to 5 or less Oes and high resistance rate of change is especially obtained by the spin bulb film of this invention, the thickness is desirable.

[264] The NiFe alloy which minded [ Co alloy /, such as Co, CoFe, CoNi, and CoFeNi, /, NiFe alloy, or those minating composition, for example, interlayer, ] 0.3-1.5nm thin Co is used for a magnetization free layer. And the thickness of a magnetization free layer has desirable 1-10nm.

[265] Table 12 is a table in which having set the thickness of a magnetization fixing layer (magnetization fixing layer) constant 2.5nm, and having shown the relation between the thickness of a magnetization free layer, and resistance rate-of-change  $\Delta R/R$ . As shown in Table 10, in this invention, magnetization free thickness is desirable, especially in order that 2-5nm may obtain high resistance rate of change.

[266]

Table 7]

12

磁化自由層 厚さ (nm)	強磁性層 A = 強磁性層 B 厚さ (nm)	抵抗変化率 $\Delta R/R^*$ 磁化自由層が CoFe 単層 (%)	抵抗変化率 $\Delta R/R^{**}$ 磁化自由層が中間層後に 1nm Co をはさんだ NiFe (%)
1	2.5	6.2	5.7
2	2.5	7.5	7.0
3	2.5	7.9	7.2
4	2.5	7.8	7.2
5	2.5	7.5	7.1
6	2.5	6.9	6.4
7	2.5	6.6	6.0

強磁性層 A と強磁性層 B は同じ厚さで CoFe 合金を用いた。

Table 13 is a table in which having set magnetization free layer thickness constant 4nm, and having shown the relation between the thickness of the ferromagnetic layer A of a magnetization fixing layer, and resistance rate-of-change  $\Delta R/R$ . As shown in Table 11, it is desirable to have the relation of  $-0.33 \leq \{t(F)-t(P)\}/t(F) \leq 0.67$  between thickness [ of a 2-5nm magnetization free layer ]  $t(F)$  and thickness [ of the ferromagnetic layer A ]  $t(P)$  in order to obtain high resistance rate of change.

[267]

Table 8]

13

磁化自由層厚さ $t(F)$ (nm)	強磁性層 A 厚さ $t(P)$ (nm)	抵抗変化率 $\Delta R/R$ (%)	$(t(F) - t(P))/t(P)$
4.5	1	4.7	0.78
4.5	1.5	6.9	0.67
4.5	2	7.1	0.56
4.5	3	7.9	0.33
4.5	4	7.7	0.11
4.5	5	7.3	-0.11
4.5	6	6.8	-0.33
4.5	7	5.9	-0.66

磁化自由層は CoFe 合金

強磁性層 A と強磁性層 B は CoFe 合金

強磁性層 B の厚さは 3nm

metals, such as Ta, Nb, Zr, Cr, Hf, Ti, Mo, and W, those alloys or the oxide of these metals, a nitride, etc. are used for protective coat. It is desirable in order that protective coats of high resistance, such as a NiFe oxide, nitriding aluminum, and a tantalum-acid ghost, may especially obtain high resistance rate of change by the oxide or the nitride, for example. Since removal by etching of a protective coat becomes easy when forming the electrode and vertical bias layer which a thing thin as much as possible describes as 0.3-4nm later, the thickness is desirable. Moreover, in the

use of for example, a CoFe magnetization free layer, in the case of a NiFe magnetization free layer, Cu/Ru, Cu and Cu alloy, etc. may use a noble-metals simple substance, an alloy monolayer, or layered products, such as Ag, Au, Cu, Ir, Cu, Pt, Pd, and Re, for Ag, Ru, Ru/Ag, Ru/Cu, Cu, etc. at a protective coat. You may form high resistance protective coats, such as Ta, further on an oxide, a nitride, and a noble-metals protective coat.

[268] Making magnetization of a magnetization fixing layer and a magnetization free layer intersect perpendicularly can be carried out by the following method. That is, after carrying out in the magnetic field to which the antiferromagnetism layer 143 impressed membrane formation to the magnetic coupling layer 1442 in the cross direction, i.e., height direction, of a spin bulb element when forming a spin bulb in the case of Mn rich alloy of gamma-In systems, such as IrMn, RhMn, and RhRuMn, it heat-treats in order to, arrange the direction of a switched connection bias magnetic field of the antiferromagnetism layer 143 with \*\* on the other hand. In addition, it is more desirable for magnetic coupling layers, such as Ru, to form membranes to 1442 layers of magnetic coupling layers, since it is more strong to oxidization, although \*\*\*\*\* [ heat treatment for on the other hand arranging the direction of switched connection bias magnetic field of this antiferromagnetism layer 143 with \*\* / immediately after membrane formation of the ferromagnetic layer B ]. It is desirable in a vacuum a short time and to carry out preferably at temperature higher than  $T_b$  in a short time for 10 or less minutes and the magnetic field with which the ferromagnetic layer B is saturated completely, without this heat treatment carrying out leak after membrane formation. For example, it carries out about 1 minute at 350 degrees C at IrMn which is 300 degrees C.

[269] Next, without leaking, at least during magnetic free layer membrane formation, a magnetic field is added in the direction of the width of recording track of a spin bulb element, and a subsequent spin bulb element is formed. Although the case of the rule combination gold of PtMn or NiMn also has the same antiferromagnetism layer 143 -- the antiferromagnetism layer of a gamma-Mn system -- differing -- not necessarily -- the membrane formation to the ferromagnetic layer B -- the inside of a magnetic field -- it is not necessary to carry out -- subsequent heat treatment -- the elevated temperature of 200 degrees C or more -- it is necessary to carry out preferably at 270-350 degrees C for 1 to 20 hours for several hours After heat treatment gives a magnetic field during membrane formation of a magnetization free layer similarly, and performs subsequent spin bulb membrane formation.

[270] In addition, any antiferromagnetism layer can also perform heat treatment in spin bulb membrane formation after spin bulb membrane formation. In this case, it is desirable to add the magnetic field exceeding the joint magnetic field of the magnetic coupling layer 1442, to saturate completely magnetization of the ferromagnetic layer A and the ferromagnetic layer B in this direction (the height direction), and to heat-treat. For example, the magnetic field which ferromagnetic layer B / magnetic coupling layer / ferromagnetic layer A adds during heat treatment since the joint magnetic fields of Ru are about 6 kOe(s) in CoFe2 nm/Ru0.9 nm/CoFe2nm has 7 or more desirable kOes. In order to make small the magnetic field added at the time of this heat treatment, it is desirable to heat-treat, before processing a spin bulb film into an element configuration. After processing, since [ of an anti-magnetic field ] it is based on an element configuration, a strong magnetic field is needed saturating the ferromagnetic layer A and the ferromagnetic layer B.

[271] Magnetization of the magnetization fixing layer 144 is made to fix towards desired by the above method. However, when the above-mentioned heat treatment is strong, it becomes difficult for the magnetization free layer 146 and the easy axis of the lower shield 11 to make it intersect perpendicularly with magnetization of a magnetization fixing layer toward the height direction of a spin bulb element like a magnetization fixing layer. In order to turn a magnetization free layer and the easy axis of a lower shield in the direction of the width of recording track, in the resist are process in a recording head, it is desirable to add the degree about magnetic field of necessary minimum with which a shield and a magnetization free layer are saturated in the direction of the width of recording track, for example, 100-300 Oes, and to stabilize the easy axis of a shield or a magnetization free layer in the direction of the width of recording track. Moreover, as for a lower shield, it is desirable to stabilize an easy axis in the direction of the width of recording track with heat treatment beforehand before spin bulb membrane formation.

[272] What CoPt, CoPtCr, etc. which were formed on grounds, such as a hard magnetic film, for example, Cr, and rCo, carried out the laminating of the ferromagnetism layer 151 and the antiferromagnetism layer 152 to the vertical bias layer one by one, and made the ferromagnetic layer hard is used with the element structure of the ABATTOJI cushion type shown in drawing 17 , i.e., the element structure which removed the width-of-recording-track edge of a magnetization free layer, and formed the vertical bias layer there. The antiferromagnetism layer 152 may be formed first and, next, the ferromagnetic layer 151 may be formed. The magnetic thickness ratio of the ferromagnetic layer by which switched connection bias was carried out by the vertical bias ferromagnetism layer to a magnetization free layer, i.e., a hard magnetic layer, and the antiferromagnetism film in order to have obtained the steep reproduction sensitivity profile in a width-of-recording-track edge corresponding to the future \*\* truck, and LB (Ms-t)/(Ms-t) F Setting or less is two is desirable. If a magnetization free layer becomes thin to about 3-6 nmTs by 2-5nm \*\* or magnetic thickness, it

LB (Ms-t)/(Ms-t) F. In order to carry out to two or less, a vertical bias ferromagnetism layer also becomes very thin, for example, it is set to 12 or less nmT by magnetic thickness.

[273] However, generally, by the hard magnetic film, if it becomes thin to 10nm thick intensity, high coercive force will become difficult to get. For example, what was the high coercive force of 2000Oe in the CoPt hard magnetic film whose Ms is 1T at 20nm \*\* falls to 800Oe(s) in 10nm. On the other hand, in a ferromagnetic / antiferromagnetism film type vertical bias layer, an exchange bias magnetic field increases and fixing becomes firm, so that a ferromagnetic 151 becomes thin. For example, the coercive force which was 80Oe(s) at 20nm \*\* in the vertical bias layer which carried out the laminating of the IrMn of NiFe whose Ms is 1T, and 7nm \*\* increases even to 160Oe(s) in 10nm \*\*. These 160Oe(s) are values which have an actual result by the conventional MR head. Therefore, it is desirable to use a ferromagnetic / antiferromagnetism film type vertical bias layer in the field where magnetization free layer thickness is very thin, for example, a field in which it becomes 5nm thick less or equal.

[274] Furthermore, it is desirable when it fully removes a Barkhausen noise in the vertical bias layer of ferromagnetic 151 / antiferromagnetism film 152 that the saturation magnetization of a ferromagnetic 151 is almost equal to the saturation magnetization of a magnetization free layer, or it is larger than it by as small the vertical bias magnetic field as possible. That is, although a NiFe alloy is sufficient as a ferromagnetic 151, a NiFeCo alloy with more large saturation magnetization, a CoFe alloy, Co, etc. are more desirable. If a disclosure magnetic field is strengthened, a Barkhausen noise is removed by enlarging the thickness using the small film of saturation magnetization as a ferromagnetic 151 and it will become the narrow width of recording track especially, the fall of a reproduction output will be caused.

[275] In addition, although the case where a vertical bias layer was formed was shown by drawing 17 without moving all spin bulb films, you may carry out etching removal to the ground layer 141. However, in order to keep the crystallinity of a ferromagnetic layer good, it is desirable to leave the ground layer 142 at least and to use the crystalline improvement effect as the depth in which it \*\*\*\*\*s before forming a vertical bias layer. From a viewpoint of a thickness control, it is desirable to \*\*\*\*\* the thicker antiferromagnetism layer 143 a little, to weaken the exchange bias, and to obtain the vertical bias layer of a good hard film property. You may give the vertical bias layer which ends etching to a nonmagnetic interlayer's middle and consists of a 151/antiferromagnetism film 152 of ferromagnetics on it. In addition, in order [ for a crystalline improvement ] to weaken the magnetic coupling of a magnetization fixing layer, the antiferromagnetism layer 143, and a vertical bias layer, you may form the very thin ground layer 153 as well as the ground layer 143 in the bottom of a ferromagnetic 151. In order to stop reduction of the magnetic coupling of a magnetization free layer and a vertical bias layer to the minimum, the thickness of the ground layer 153 has desirable 10nm or less.

[276] When using a hard magnetic film, it is desirable to arrange the saturation magnetization of a magnetization free layer and a hard magnetic film similarly. However, it is usually difficult to produce the hard magnetic film of the high saturation magnetization which is equal to high saturation magnetization free layers, such as CoFe. Then, the method of maintaining balance with saturation magnetization with a magnetization free layer is suitable for removing a Barkhausen noise by the small vertical bias magnetic field using the film of high saturation magnetization like FeCo as a ground of a hard magnetic film.

[277] The same antiferromagnetic substance as what was used for the spin bulb film can be used for the antiferromagnetism film 152. However, the exchange bias magnetic field of the height direction and the antiferromagnetism film 152 of a vertical bias layer needs to make the direction of the width of recording track, and the exchange bias magnetic field of the antiferromagnetism layer of a spin bulb cross at right angles mutually. Then, after for example, ] heat treatment prescribes the direction of an exchange bias magnetic field of the antiferromagnetism layer which both blocking temperature Tb is changed and has high Tb first, A mutual exchange bias magnetic field can be made to intersect perpendicularly by setting up the direction of an exchange bias magnetic field of the antiferromagnetism film which has low Tb, heat-treating low temperature more to the antiferromagnetism film which has Tb lower than it, and keeping stable the direction of exchange bias of a high Tb antiferromagnetism layer.

[278] On the antiferromagnetism film 152, specifically with heat treatment of PtMn, PdPtMn, etc. Although the antiferromagnetism film which discovers HUA is sufficient, Tb which a magnetization fixing layer can heat-treat at stable temperature is 200-300 degrees C. If the antiferromagnetic substance with Tb higher than it, i.e., IrMn, PtMn, PdPtMn, etc. are used for the antiferromagnetism layer of a spin bulb film, RhMn, IrMn, RhRuMn, FeMn, etc. The direction of exchange bias of the antiferromagnetism film 152 can be specified in the direction of the width of recording track, without disturbing the direction of magnetization fixing layer magnetization of a spin bulb film at the assist cure heat treatment process mentioned above. That is, \*\*\*\* can make vertical bias and magnetization fixing layer magnetization intersect perpendicularly good, even if the blocking temperature gradient between both antiferromagnetism films is dozens of degrees C by using the property which pin magnetization stabilizes rapidly

slow at the blocking temperature which is the feature of this invention. When IrMn, FeMn, RhMn, RhRuMn, rMnPt, CrMn, etc. which can give an exchange bias magnetic field to the antiferromagnetism film 152 by membrane formation among a magnetic field are used, heat treatment moreover, to give an unnecessary hatchet. No matter what layer [ antiferromagnetism ] the direction of a bias magnetic field of the antiferromagnetism layer 143 of a spin bulb film may not be disturbed and it may use for the antiferromagnetism layer 143 of a spin bulb film, the direction of vertical bias and the magnetization fixing layer magnetization direction can be made to intersect perpendicularly.

[279] On the other hand, as shown in drawing 27 , vertical bias can be added to a magnetization free layer also with the structure which carried out etching removal only of the protective coat 147 of the width-of-recording-track edge of magnetization free layer, and carried out the switched connection laminating of the antiferromagnetism film on it. As for the vertical bias layer 15, it is desirable to mind the buffer layer 1511 for strengthening switched connection with a magnetization free layer as the antiferromagnetism layer 152 and its ground. As for this buffer layer 1511, it is desirable that it is the ferromagnetic layer which consists of Fe, Co, nickel, etc. The convention of the magnetization direction of vertical bias is the same as that of the case of the vertical bias of the 151/antiferromagnetism layer 152 of ferromagnetic layers. The vertical bias method using the antiferromagnetism layer has the advantage which can suppress a Barkhausen noise, without generating an excessive vertical bias magnetic field like a hard magnetic-film method, and causing the sensitivity fall of a head.

[280] (Form 3 of operation) The 3rd operation form of this invention is shown in drawing 28 . As for drawing 28 , the structure of a spin bulb film differs from drawing 21 . In drawing 27 , the spin bulb film 14 formed on the lower gap 12 of Ta, Nb, Zr, The nonmagnetic ground layer 141 with a thickness [ , such as Hf, ] of 1-10nm, It consists of protective coats 147 with a thickness of 0.5-10nm the 2nd ground layer 142 with a thickness of 0.5-5nm, the magnetization free layer 146, the interlayer 145 with a thickness of 0.5-4nm, the magnetization fixing layer 144, the antiferromagnetism layer 143, and if needed if needed. The magnetization free layer (free layer) 146, an interlayer 145, the magnetization fixing layer 144, and the antiferromagnetism layer 143 are the same composition as the operation form 2 here.

[281] When the alloy which makes a principal component Au, Cu, Ru, Cr, nickel, Ag, Pt, Rh, or them was used and a CoFe alloy is used especially for a magnetization free layer, the thermal resistance of resistance rate of change can be used to the ground layer 142.

[282] In drawing 27 , the spin bulb element 13 is constituted by the same vertical bias layer 15 of a couple as drawing 17 , and the electrode 16 of a couple together with the spin bulb 14. The upper gap layer 17 and the upper shield 18 are constituted still like drawing 21 on it.

[283] (Form 4 of operation) Drawing 29 is the operation form of further others of this invention, and shows the example at the time of applying this invention to dual type spin bulb structure.

[284] In drawing 29 , like the case of drawing 21 of the operation form 2, and drawing 27 of the operation form 3, the vertical bias layer 15 of a couple, the electrode 16 of a couple, the vertical bias layer 15, and the spin bulb element 13 that consists of a spin bulb film 14 are formed on the lower shield 11 and the lower gap 12, and the upper gap 17 and the upper shield 18 are formed on it. However, the interval of an electrode 16 and the composition of the spin bulb film 14 differ from drawing 21 and drawing 27 .

[285] The spin bulb film 14 Ta, Nb, Zr, The nonmagnetic ground layer 141 with a thickness [ , such as Hf, ] of 1-10nm and the need are accepted. The 2nd ground layer 142 with a thickness of 0.5-5nm, the antiferromagnetism layer 143, the magnetization fixing layer 144, the interlayer 145 with a thickness of 0.5-4nm, the magnetization free layer 146, the 2nd interlayer 148 with a thickness of 0.5-4nm, It consists of protective coats 147 with a thickness of 0.5-10nm the 2nd magnetization fixing layer 149, the 2nd antiferromagnetism layer 150, and if needed.

[286] The laminating magnetization fixing layer which becomes at least one side of the magnetization fixing layer 144 and the magnetization fixing layer 149 from the same ferromagnetic layer A and same magnetic coupling layer as drawing 17 , and the ferromagnetic layer B is used. the combination of the monolayer magnetization fixing layer of the former [ layer / 1 magnetization fixing / 149 / layer / magnetization fixing / 144 / a SyAF magnetization fixing layer and ] and 2 -- to the magnetization fixing layer 144, the combination of a SyAF magnetization fixing layer can be conversely used in a SyAF magnetization fixing layer and the magnetization fixing layer 149 in the combination of the conventional monolayer magnetization fixing layer, or the both sides of 3 magnetization fixing layer 149 and the magnetization fixing layer 144 / and

[287] Although the vertical bias layer 15 is the so-called ABATTO junction type of element structure After using the same vertical bias layer 15 as drawing 17 , drawing 27 , and drawing 28 into the lift-off method, using a photoresist as mask and carrying out etching removal of the width-of-recording-track edge of a spin bulb film, by methods, such as sputter, vacuum evaporation, and ion beam membrane formation forming the vertical bias layer 15 -- facing -- etching removal of the spin bulb film 14 -- at least -- the conductor layer of the spin bulb film 14 -- \*\*\*\*\* -- it is desirable to carry out like For example, when the antiferromagnetism layer 143 is a gamma-Mn system alloy like IrMn,

is desirable to leave a part of antiferromagnetism layer 143 at least.

288] If it leaves the conductor section to a width-of-recording-track edge, since the contact resistance of an BATTO junction will fall, it is easy to realize the spin bulb element 13 of low resistance, and, for this reason, a long head can be realized to static electricity. Of course, etching removal of all the spin bulb films of a width-of-recording-track edge may be carried out, and a vertical bias layer may be formed.

289] Although an electrode 16 may be put in block with a vertical bias layer and lift-off formation may be carried out, an electrode spacing and the interval of a vertical bias layer are mostly in agreement in this case. Or it is good also the so-called lead exaggerated RAID structure which separated electrode formation with vertical bias layer formation, and narrowed and formed the electrode spacing from the interval of a vertical bias layer. When it was lead exaggerated RAID structure and a hard magnetic layer is used especially for a vertical bias layer, the influence of the closure magnetic field from a hard magnetic layer can be shut up near [ where the laminating of the spin bulb film is carried out to the electrode ] the width-of-recording-track edge section, and there is a merit which can be specified to the sensitivity profile sharp of the direction of the width of recording track of the regenerative-track width of face specified by inter-electrode with high degree of accuracy. In high-density record to which especially regenerative-track width of face serves as submicron one, the merit becomes clearer compared with the conventional method. Naturally the lead exaggerated RAID structure is applicable also to the operation form of drawing 21 or drawing 27.

290] (Form 5 of operation) Drawing 30 is the operation form of further others of this invention. Like the form 2 of operation shown in drawing 21, a lower shield and a lower cap (not shown) are formed on a substrate (not shown), the spin bulb film 13 is further formed on it, and although not further illustrated on it, an upper cap, an upper shield, and the Records Department are formed. The vertical bias layer 15 and electrode 16 of a couple are formed in the width-of-recording-track ends of the spin bulb film 13. The case where the layered product which consists of the ground layer 153, a ferromagnetic 151, and an antiferromagnetism film 152 was used for a vertical bias layer as an example was shown. Naturally hard magnetic films, such as CoPt, can be used for a vertical bias layer.

291] An electrode 16 forms low resistance metals, such as Ta/Au/Ta, using the material included at least, an electrode spacing LD is formed more narrowly than the vertical bias interlayer spacing HMD, and the spin bulb film 13 and an electrode 16 have the field which carries out field contact near the width-of-recording-track ends. Although a vertical bias layer and an electrode are usually formed of a lift off, you may form them by the ion milling method, the reactive-ion-etching method, etc. Although a process process becomes complicated, a drive process is especially suitable for highly precise electrode formation.

292] In spin bulb film 13 field of electrode 16 directly under in which the vertical bias layer 15 does not exist The resistance of an electrode compares with the resistance of a spin bulb film. when small enough, to the case of 1/10 or less If magnetization of the magnetization free layer 146 of a spin bulb film is mostly specified in the direction of the width of recording track when a medium magnetic field is zero mostly, since reproduction sensitivity will furthermore be reduced sharply in parts other than inter-electrode [, such as directly under / of a spin bulb film / electrode /, ] An electrode spacing LD can prescribe regenerative-track width of face, and the steep reproduction sensitivity distribution in a width-of-recording-track edge can be realized.

293] Since a field surface of action can furthermore take the spin bulb film 13 and the sufficiently large electrode 16 compared with the usual ABATTO junction method, the contact resistance of an electrode and a spin bulb can control small enough, as a result, the spin bulb element of low resistance can be realized, and, moreover, a magnetoresistance-effect head strong against ESD can be realized in a low noise.

294] In order to raise recording density here from now on and to narrow regenerative-track width of face, it is necessary to narrow an electrode spacing LD. On the other hand, if an electrode spacing becomes remarkably narrow, it will become difficult to narrow the width of face of an element, i.e., height, more than it. Therefore, it is desirable to make HD larger than LD when manufacturing a head with the sufficient yield. Specifically, in order to keep good the field at the time of head mass production, about the height which determines a size with machining, about 0.5 micrometers and more than it are required, and when regenerative-track width of face narrows in 0.5 micrometers or less, it is desirable to set up HD more greatly than LD. However, the following problems occur in that case.

295] The 1st problem is that a reproduction output decreases, in order that resistance of the reproduced spin bulb film field may decrease. It was avoided by raising field resistance of a spin bulb film to this problem. Although it was difficult to obtain high field resistance since fixing thickness was conventionally thicker than the magnetization fixing layer of a monolayer, as shown in Table 14 and 15, by this invention, it is compatible in high field resistance of 6ohms or more, and 8% or more of high resistance change with the usual SyAF fixing layer by suppressing the sum total of the thickness of the thickness of a magnetization fixing layer, a nonmagnetic interlayer, and a magnetization free layer to 14nm thick less or equal.

296]

able 9]

14

ピンバルブ膜構成: Ta (5nm)/Au (2nm) IrMn (7nm)/強磁性層B/ 磁化結合層/ 強磁性層A/ 中間非磁性層/ 磁化自由層/ Ta

強磁性層B 厚さ (nm)	磁化結合層 厚さ (nm)	強磁性層A 厚さ (nm)	非磁性中間 層厚さ (nm)	磁化自由層 厚さ (nm)	強磁性層B～磁化自 由層合計厚さ (nm)	R <sub>s</sub> (Ω)	ΔR/R (%)
CoFe (2nm)	Ru (0.9nm)	CoFe (3nm)	Cu (2nm)	CoFe (0.5nm)/NiFe (2.5nm)	9.9	13.5	8.3
CoFe (1.5nm)	Ru (0.8nm)	CoFe (3nm)	Cu (2nm)	CoFe (0.5nm)/NiFe (4nm)	10.8	19.5	8.7
CoFe (1.5nm)	Ru (0.8nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (3nm)	9.9	19.5	9.7
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2nm)	Co (1nm)/NiFe (5nm)	12.9	18.2	8.9
CoFe (1.5nm)	Ru (0.9nm)	CoFe (1.5nm)	Cu (2nm)	Co (1nm)/NiFe (3nm)	9.9	22.8	8.1
CoFe (2nm)	Ru (0.9nm)	CoFe (2.5nm)	Cu (2nm)	CoFe (3nm)	10.4	19.4	10.7
CoFe (2nm)	Ru (1nm)	CoFe (2.5nm)	Cu (2.5nm)	Co (1nm)/NiFe (4nm)	13	18	8.1
CoFe (2.2nm)	Ru (0.8nm)	CoFe (2.5nm)	Cu (2nm)	CoFe (2nm)/NiFe (4.5nm)	14	18	8.7
CoFe (3nm)	Ru (0.9nm)	CoFe (3nm)	Cu (3nm)	CoFe (1nm)/NiFe (7nm)	17.8	13	6.5
CoFe (3nm)	Ru (0.9nm)	CoFe (3nm)	Cu (3nm)	CoFe (3nm)/NiFe (2nm)	14.8	12	7.2
CoFe (2.5nm)	Ru (0.8nm)	CoFe (3nm)	Cu (2.5nm)	CoFe (1nm)/NiFe (7nm)	16.8	14.7	7.3
CoFe (3nm)	Ru (0.7nm)	CoFe (3nm)	Cu (3nm)	CoFe (5nm)	14.7	12.5	8.2

297]

able 10]

15

ピンバルブ膜構成: Ta (5nm)/NiFe (2nm) PtMn (7.5nm)/強磁性層B/ 磁化結合層/ 強磁性層A/ 中間非磁性層/ 磁化自由層/ Ta

強磁性層B 厚さ (nm)	磁化結合層 厚さ (nm)	強磁性層A 厚さ (nm)	非磁性中間層 厚さ (nm)	磁化自由層 厚さ (nm)	強磁性層B～磁化自 由層合計厚さ (nm)	R <sub>s</sub> (Ω)	ΔR/R (%)
Co (2nm)	Ru (0.9nm)	Co (2nm)	Cu (2.5nm)	Co (1nm)/NiFe (2nm)	10.4	23.5	18.6
Co (2nm)	Ru (0.9nm)	Co (2nm)	Cu (2.5nm)	Co (0.5nm)/NiFe (2nm)	9.9	19.7	7.9
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (1nm)/NiFe (2nm)	9.7	18.6	8.7
CoFe (2nm)	Ru (0.9nm)	CoFe (2nm)	Cu (2.5nm)	CoFe (3nm)	10.4	18.3	9.1

298] In order to realize high resistance rate of change using such an ultra-thin spin bulb film 1) CoFe with a stable c phase, CoNi, and a CoFeNi alloy are used for the ferromagnetic layer A of a magnetization fixing layer, and the paramagnetic layer B, 2) Co, CoFe, CoNi, and a CoFeNi alloy are used also for a magnetization free layer at least near the interface with a middle non-magnetic layer, 3) It is desirable to use the antiferromagnetism layer containing noble-metal elements, such as PtMn, PtPdMn, IrMn, RhMn, and RhRuMn, for an antiferromagnetism film.

299] The 2nd problem in the case of setting up HD more greatly than LD is generating of a Barkhausen noise. With the spin bulb element of the ABATTO junction method the conventional electrode spacing and whose interval HMD of vertical bias film correspond mostly, HMD becomes smaller than HD, the direction of HD becomes a long rectangle configuration, magnetization of a magnetization free layer becomes easy to turn to the configuration of a magnetization free layer in the height direction where an anti-magnetic field is weak, and, as a result, a Barkhausen noise generates it. On the other hand, in this invention, the configuration of a spin bulb film does not say that it becomes easy to turn to magnetization of a magnetization free layer in the height direction since HMD is more greatly [ than HD ] long in the direction of the width of recording track, and for this reason, removal of a Barkhausen noise is easy and can improve head manufacture ] the yield about this point.

300] As an example, it is 1HD=0.5micrometer, LD=0.45micrometer, HMD=1.3micrometer, 2HD=0.4micrometer, LD=0.35micrometer, HMD=0.8micrometer, etc., and is a book.

301] In addition, although the case where the magnetization fixing layer had been arranged between a magnetization free layer and a substrate was shown in drawing 29, it is applicable similarly about the case where a magnetization

ee layer exists between a substrate and a magnetization fixing layer.

[302] (Form 6 of operation) The form of the operation of further others of this invention is shown in drawing 31 . The substrate which is not illustrated, a lower shield, and a lower gap are formed, and the vertical bias layer 15 of a couple formed on it of dry processes, such as the lift-off method, ion milling, and reactive ion etching. Although the case here it consisted that the form 2 of operation showed drawing 29 as an example of a vertical bias layer of a layered product of the ferromagnetics 151, such as the antiferromagnetism films 152, such as the ground layer 153 and IrMn suitable for the same antiferromagnetism layer, RhMn, and CrMn, CoFe, NiFe, and Co, was shown, each of other vertical bias layer shown with the form 2 of operation is applicable.

[303] Besides, the spin bulb film 13 is formed. In order to give the bias magnetic field from a vertical bias layer effectively to the magnetization free layer 143, as for the spin bulb film 13, it is more more desirable than a magnetization fixing layer that the vertical bias layer 15 and the magnetization free layer 143 make it easy to arrange the magnetization free layer 143 and to approach a substrate side. In order to give the bias magnetic field from a vertical bias layer effectively to a magnetization free layer, as for the thickness of the ground layers 141 and 142 of the magnetization free layer 143, it is desirable that it is 10nm. Moreover, the field surface of action of the spin bulb film 13 and the vertical bias 15 is desirable when making it small as much as possible suppresses a Barkhausen noise.

[304] On the spin bulb 13, the electrode 16 of a couple is formed by the lift-off method, the ion milling method, and the reactive-ion-etching method. Although not illustrated, an upper gap, an upper shield, and the Records Department are further formed on it.

[305] Moreover, with the form 5 of operation having shown, similarly, by making it smaller than HMD more greatly than LD, HD does not have the reproducing head suitable for the \*\* width of recording track, and can be manufactured with the sufficient yield. Moreover, by setting sum total thickness of a magnetization fixing layer, a nonmagnetic interlayer, and a magnetization free layer to 14nm or less, the resistance of the spin bulb film 13 can be raised, a production output can be heightened, and a high sensitivity magnetoresistance-effect head can be obtained.

[306] \*\*\*\* 6.

Form : the thermal resistance and the mirror plane of the 7th operation)

[307] First, before introducing the example of this operation form, the technical problem recognized in process in which this invention person results in this operation form is explained.

[308] The technical problem which this invention person has recognized can be divided roughly into below in putting highly efficient spin bulb film (it being hereafter described as SV film) in practical use.

[309] (1) Thermal resistance is bad (receiving especially initial process annealing).

[310] (2) When aiming at much more improvement in reproduction sensitivity, MR rate of change runs short.

[311] (3) When a magnetosensitive layer is constituted from a CoFe alloy-layer monolayer from which comparatively big MR rate of change is obtained, magnetostriction control cannot be performed, and good soft magnetic characteristics are not obtained.

[312] The technical problem of these SV films is explained in full detail below.

[313] (1) As general composition of the magnetosensitive layer of heat-resistant SV film, NiFe (several nm)/Co (about 1nm) and NiFe(several nm)/CoFe (about 1nm) are known. As SV membrane structure (a) using such a magnetosensitive layer Ta(5nm)/NiFe(10nm)/Co(1nm)/Cu(3nm)/CoFe(2nm)/IrMn (7nm) / Ta (5nm)

) Ta(5nm)/Cu(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

\*\*\* is mentioned.

[314] By SV film which was described above, thing MR degradation will arise about 20% or more to MR value at the time of as-depo at a relative ratio by about [ 250 degree-Cx4H ] process annealing. For example, by SV film of (a), 4.4% of MR rate of change at the time of as-depo will deteriorate 20% or more by the relative ratio to the time of 4.7% and as-depo after annealing which is 250 degree-Cx3H. This annealing process is a process it is [ a process ] indispensable on head production. After annealing of 250 degree-Cx3H, about 20% of degradation produces MR rate of change at the time of as-depo as compared with 6.5% and the time of as-depo to SV film of (b) which does not use \* and NiFe as a magnetosensitive layer being 8.1%. For the moment, the technique improved without sacrificing magnetic properties for degradation of such MR rate of change, i.e., a heat-resistant remedy, is not found out.

[315] Although a SV film which has higher MR rate of change is desired in the magnetic head towards densification, MR rate of change obtained at the time of as-depo is remarkably reduced in a thermal process with the indispensable reduction process top of a head by SV film obtained by present as mentioned above. This is the problem which must surely be solved when developing the MR head which was with 10 or more Gdpsis and was made to correspond to recording density [ like ].

[316] (2) In order to attain the improvement quantity MR rate of change of MR rate of change by use of a reflection effect With how MR rate of change obtained at the time of as-depo shown by (1) is maintained after a thermal process

is also important how the absolute value of MR rate of change is raised or how even if MR rate of change of full potential is not obtained in the time of as-depo, a film with which MR rate of change good after a thermal process is obtained is realized.

[317] the range with the GMR effect shorter than an electronic mean free path -- if -- since the number of times which receives spin dependence dispersion increases so that there are many number of layers of the cascade screen of a magnetic layer/non-magnetic layer, MR rate of change becomes large. However, like SV membrane structure, since there are only units, such as a magnetization fixing layer / nonmagnetic interlayer / magnetosensitive layer, in the structure of the GMR film actually used with a head, generally it is short thickness from the mean free path, and is small in MR rate of change.

[318] In order to improve this, as structure which increased the number of layers, a magnetization fixing layer is made vertical two-layer, and the dual spin bulb film (or SHIMETORI-spin bulb film (it is hereafter described as a D-SV film)) which has arranged the magnetosensitive layer in the meantime is known. Although this is also one cure, by the time it solves all practical problems, it will not have resulted at a present stage. For example, it is with the D-SV film from which the ground for a magnetosensitive layer serves as a nonmagnetic interlayer, the soft magnetic characteristics  $H_k$ , for example, the anti-magnetic field, of a magnetosensitive layer. It is difficult to satisfy all the magnetostrictions  $\lambda$  etc. Furthermore, although the one where the blocking temperature of the two-layer antiferromagnetism film which fixes magnetization two-layer [ these ] is more nearly equal is desirable when the magnetization fixing layer of two upper and lower sides is used, it is difficult to make equal the property of the antiferromagnetism film located in the bottom in fact, and the antiferromagnetism film located in an upper layer side through a nonmagnetic interlayer or a magnetosensitive layer. Therefore, although the D-SV film from the point of MR rate of change is desirable composition, many technical problems are included from a viewpoint of practicality.

[319] Then, it is a mirror plane as one means by which the antiferromagnetism film put in practical use now raises the property of SV film of the general structure of one layer. This arranges a reflective film on one side or the vertical both sides of a basic unit of a magnetic layer / nonmagnetic interlayer / magnetic layer, reflects an electron elastically, and lengthens the mean free path within the basic unit of a GMR film. [ of a GMR film ]

[320] Conventionally, since only the distance of the mean free path which it should originally have since inelasticity-dispersion was received was not able to move an electron and spin dependence dispersion more than the thickness of the basic unit of a GMR film was not able to be received, it was losing on the vertical layer of the basic unit of a GMR film in MR rate of change. If it uses the reflective film of vertical both ideal layers, seemingly, a GMR basic unit becomes an infinite artificial grid and infinite equivalence, and since only the part of the mean free path which originally moves can receive spin dependence dispersion now, MR rate of change will improve. Thus, the reflective film on the outside of the magnetic layer located in a nonmagnetic interlayer's upper and lower sides itself demonstrates an effect enough by the reflection which is not dependent on spin even if it is not a reflective film depending on spin.

[321] The above-mentioned effect demonstrates an effect also not only in general SV membrane structure but in a D-SV film. However, there are many number of layers from the first, and there is no effect of a reflective film in the artificial grid of the infinite number of layers which has received spin dependence dispersion by the original mean free path. Thus, SV membrane structure with few number of layers from the first has a larger effect.

[322] A mirror plane which was conventionally mentioned above

[323] (c) Si substrate / NiO(50nm)/Co(2.5nm)/Cu(1.8nm)/Co(4nm)/Cu(1.8nm)/Co(2.5nm)/NiO (50nm)

(d) Si substrate / NiO(50nm)/Co(2.5nm)/Cu(2nm)/Co(3nm)/Au (0.4nm)

(Ref.J.R.Jody et.al., IEEE Mag.33 No.5.3580 (1997)) (e) MgO substrate / Pt(10nm)/Cu(5nm)/NiFe(5nm)/Cu(2.8nm)/Co(5nm)/Cu (1.2nm) / Ag (3nm)

(Japan Institute of Metals 1997 spring convention [ besides Ref. river part Yasuhiro ] lecture outline p142)

(f) Si substrate / Si<sub>3</sub>N<sub>4</sub> / (200nm) Bi<sub>2</sub>O<sub>3</sub> / (20nm) Au(4nm)/NiFe(4nm)/Cu(3.5nm)/CoFe (4nm)

(Ref.D.Wang et al.,IEEE Mag 32 No.5.4278(1996))

In addition, the portion which attached the underline among SV membrane structures mentioned above is a portion considered to be a specular reflection film.

[324] By SV film of the above (c), the specular reflection film with which vertical both layers consist of an oxide is used. The way which used the insulating oxide with a potential barrier higher than a metal in order to cause reflection of an electronic wave, even if it thinks simply is a mirror plane. Furthermore, since a NiO film is also an antiferromagnetism film while it is an oxide reflective film, it has also played the role which fixes magnetization of the magnetic layer which is in contact with NiO. Although the above-mentioned composition is a D-SV film, antiferromagnetism films, such as a normal SV film and a reversal SV film, are considered that the specular reflection of one side is acquired even for the structure of one layer. However, there are some faults by such film and it is not

actical at a present stage.

325] First, the switched connection force is weak and practicality of NiO is low. In a weak coupling magnetic field, a magnetization direction of a magnetization fixing layer becomes unstable by the disclosure magnetic field from a record medium, and there is a possibility of changing an output. Furthermore, in using an oxide layer for the upper layer, make it NiO -- moreover, carry out using another oxide as a cap layer -- contact resistance with a lead electrode will become large. Since it becomes easy to cause ESD (electro static discharge : electrostatic discharge), increase of contact resistance is not desirable. Furthermore, when CoFe is used for a magnetosensitive layer, if fcc (111) orientation of the CoFe is not carried out, it turns out that a good soft magnetism is unrealizable. When a magnetosensitive layer is located in a lower layer, since the buffer layer of fcc (111) orientation will be lost for CoFe, being compatible [ with soft magnetic characteristics ] of using an oxide layer as a ground of a magnetosensitive layer comes difficult.

326] Moreover, by SV film of (d), the antiferromagnetism [ a reflective film-cum- ] film of NiO is used for a ground layer, and Au layer on the front face of a film serves as a reflective film further. Moreover, similarly, SV film of (e) is also a reflective film, uses the potential difference on Ag film and the front face of a film, and Ag film on the front face of a film is a mirror plane. Although the reason the effect was acquired by noble-metals film like Au or Ag as a reflective film on the front face of a film is not clear, since the surface diffusion on the front face of a film tends to happen [ noble metals ] to the reference of (d) from transition metals as one reason, flat nature becomes high and it is indicated by the noble-metals film front face that it is for being easy to pull out a reflection effect.

327] It is advantageous at the point which can do small contact resistance with the lead electrode which was a trouble at the time of an oxide reflective film by the reflective film which used for the film front face a metal membrane which is as described above. However, the mirror plane on the front face of a film of a noble-metals film like Au or Ag. That is, it is rare that the front face of SV film is exposed as it is in actual MR element and an actual MR head, and, usually the laminating of a certain film is carried out on SV film.

328] For example, in a shielded type MR head, the laminating of the upper magnetic-gap film which consists of an alumina etc. is carried out on SV film. It is a mirror plane as indicated by the reference of (d). If the laminating of another film is carried out on the film with which it used the reflection effect on the front face of a film from the first, naturally a reflection effect will change. Thus, the membrane structure to which MR property is changed with the film / which a laminating is carried out on SV film has a problem in respect of practical use.

329] If the laminating of the Ta film usually well used for Au film front face of SV film of (d) as a protective coat is actually carried out, it is reported that a reflection effect is lost. Thus, the mirror plane on the front face of a film

330] Although SV film of (f) uses Au film as a specular reflection film like (d), this is a mirror plane in not the reflection effect on the front face of a film but the film interface of metal membranes. The interface with NiFe by which elaborates a ground by SV film of (f), and makes Au film front face a flat as much as possible, and a laminating is carried out on it here in order that it may be known that it will be easy to carry out island growth and it may suppress it, if Au film forms membranes directly on a substrate without a suitable ground layer is made sharp.

331] However, the ground layer of (f) cannot be called practical technique. That is, it is Bi<sub>2</sub>O<sub>3</sub> about Au film. It is said that a good reflection effect can be pulled out if membranes are formed on a film and annealing is performed at 50 degrees C. the Bi<sub>2</sub>O<sub>3</sub> film with a thickness of 20nm is used as a ground (Ref.C.R.Tellier and A.J.Tosser.Size Effects in Thin Films, Chapter I.Elsevier, and 1982 --) L. I.Maissel et al., Handbook of Thin Film Technology.McGRAW-Hill Publishing Company, 1983.

332] Furthermore, Si<sub>2</sub>O<sub>3</sub> It is Si<sub>3</sub>N<sub>4</sub> with a thickness of 200nm as a membranous ground. The film is used. That is, the ground film with a total thickness of no less than 220nm was used upwards as a ground of Au film, and it has passed through the annealing process in the elevated temperature of 350 degrees C. If the thickness of 220nm will consider a bird clapper to a narrow gap increasingly in connection with densification from now on, not only becoming being remarkable and disadvantageous but practicality is very low. Furthermore, heat treatment in the elevated temperature of 350 degrees C will cause interface diffusion by the magnetic layer / nonmagnetic interlayer interface which causes basic spin dependence dispersion for a GMR film, and MR rate of change will deteriorate remarkably. This temperature is temperature from which interface diffusion also produces SV film using the Co(CoFe)/Cu/Co (CoFe) cascade screen which was [ even if ] excellent in thermal resistance.

333] (3) When using the magnetostriction control CoFe layer of CoFe as a magnetosensitive layer, fcc (111) orientation of the CoFe layer is carried out by applying the ground layer which carried out fcc (111) orientation, and it is found out that it is possible to raise soft magnetic characteristics by this. Here, Cu layer and Au layer are used as a ground layer which carried out fcc (111) orientation. However, about the magnetostriction which is another important element of soft magnetic characteristics, it was not controlled at all, and thermal resistance also found out that it was greatly dependent on a ground layer this time. For example, a membrane structure as shown below as a SV film based

the above-mentioned official report is mentioned.

34] (g) Ta(5nm)/Cu(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

Ta(5nm)/Au(2nm)/CoFe(3nm)/Cu(3nm)/CoFe(2nm)/IrMn(7nm)/Ta(5nm)

the above-mentioned film of (g), fcc (111) orientation of the Cu film is carried out. Although fcc (111) orientation of the CoFe layer on this fcc(111) Cu film is carried out and a soft magnetism can be realized (i) It cannot be said that the absolute value of  $\lambda$  is large etc. has not necessarily satisfied practicality fully with the (ii)

magnetostriction  $-14 \times 10^{-7}$ . [ with bad (after as-depo: 8.1%  $\rightarrow$  250 degree-Cx4H : 6.5% (MR rate of change deteriorates % in a relative ratio)) thermal resistance ] Although there is no clear indicator of Magnetostriction  $\lambda$ , as one criteria,  $-10 \times 10^{-7}$  to  $+10 \times 10^{-7}$  to about seven can say that it is desirable.

35] Furthermore, when it replaces with Cu as a fcc material and Au is used (film of (h)) (i) It cannot be said that practicality is not necessarily satisfied fully like the case where Cu film -- an absolute value is large -- is used with the magnetostriction  $\lambda + 33 \times 10^{-7}$ . [ with bad (after as-depo: 8.4%  $\rightarrow$  250 degree-Cx4H : 6.5% (MR rate of change deteriorates 23% in a relative ratio)) thermal resistance ]

36] The  $\theta$ - $2\theta$  scan measured and estimated the XRD pattern of the spin bulb film of the above (g) and (h). Since it was almost same d spacing value by three layer of CoFe/Cu/CoFe and had become one peak, the peak value was taken. At this time, d-(111) spacing value of the fcc orientation of three layer of CoFe/Cu/CoFe on Cu was 0.54nm, and d-(111) spacing value of the fcc orientation of three layer of CoFe/Cu/CoFe on Au was 2.086nm. Since suitable small magnetostriction value was taken when making it the mean value of d-(111) spacing value on these Cu ] and Au so that it might mention later, it turns out that too small d-(111) spacing value on Cu and too large d-(111) spacing value on Au are not desirable.

37] Thus, when using the magnetosensitive layer which consists of a CoFe layer, even if it formed membranes on a ground layer which only carried out fcc (111) orientation, the point of a magnetostriction showed that it was inadequate. In addition, CoFe is formed on nickel<sub>80</sub>Fe<sub>20</sub> which is near the zero magnetostriction and carried out fcc (111) orientation as one of the technique to which a magnetostriction is satisfied, and although the structure (the above-mentioned composition of (a)) which makes a magnetostriction zero as the whole magnetosensitive layer by about 0 Fe in magnetostriction is mentioned, this composition has the problem [ mentioned / above ] that thermal-process gradation of MR property is large.

38] As mentioned above, the conventional spin bulb film is wanted to raise the thermal resistance of a spin bulb film, since decline in MR rate of change by the thermal process is large.

39] Moreover, it is a mirror plane as an improvement measure of MR rate of change of a spin bulb film. In order for the reflective films in the conventional spin bulb film to be insulators, such as an oxide, and to use the reflection effect at the front face of a film, For example, it is a mirror plane, when increase of contact resistance with a lead electrode uses ESD or a protective coat etc. is formed on a spin bulb film. Furthermore, although using a reflection effect by the interface was also examined, as for practicality, it was very low that there was the need of preparing a ground layer coat for the reason etc. It is a mirror plane, after taking into consideration the practicality as an element or the magnetic head, since it was such.

340] Furthermore, controlling small the magnetostriction of Co system magnetic layer which consists of a CoFe alloy etc., when raising the soft magnetic characteristics of a spin bulb film is called for.

341] Especially, it is a mirror plane.

342] The magnetoresistance-effect element which has the spin bulb film which was invented in order that this operation form might cope with such a technical problem, and suppressed the fall of MR property by the thermal process, Moreover, it aims at offering the magnetoresistance-effect element which has the spin bulb film which raised MR rate of change according to the specular reflection effect after taking practicality into consideration, the spin bulb film which realized the low magnetostriction, and the spin bulb film which suppressed these thermal-process gradation further. Furthermore, it aims at offering the magnetic head and the magnetic recording medium which used record reproducing characteristics and practicality by using such a magnetoresistance-effect element.

343] The gestalt of the operation for solving hereafter the technical problem mentioned above is explained with reference to a drawing.

344] Drawing 32 is the cross section showing the important section structure of 1 operation gestalt of the magnetoresistance-effect element (MR element) of this invention. In this drawing, 1 is the 1st magnetic layer and 2 is the 2nd magnetic layer. The laminating of these [ 1st ] and the 2nd magnetic layer 1 and 2 is carried out through the nonmagnetic interlayer 3. Antiferromagnetism combination is not carried out between the 1st and the 2nd magnetic layer 1, and 2, but it constitutes the magnetic uncombined type multilayer.

345] The 1st and 2nd magnetic layers 1 and 2 are constituted by the ferromagnetic containing Co like for example, Co simple substance or Co alloy. Magnetic layers 1 and 2 may consist of NiFe alloys etc. It is desirable to use Co alloy

th which especially a bulk effect and the interface effect can both be enlarged, and big MR variation is obtained along these.

346] The alloy which added one sort or two sorts or more of elements chosen as Co from Fe, nickel, Au, Ag, Cu, Pd, Ir, Rh, Ru, Os, Hf, etc. as a Co alloy which constitutes magnetic layers 1 and 2 is used. As for the amount of alloying elements, it is desirable to consider as five to 50 atom %, and it is desirable to consider as the range of further 20 atom %. This is because there is a possibility that the interface effect may decrease when a bulk effect will not increase if there are too few amounts of alloying elements, but there are too many amounts of alloying elements inversely. When obtaining big MR variation, as for an alloying element, it is desirable to use especially Fe.

347] The 1st lower magnetic layer 1 is formed among the 1st and 2nd magnetic layers 1 and 2 on the improvement layer 4 in the magnetoresistance effect (improvement layer in MR). The improvement layer 4 in MR is formed on the non-magnetic layer (it is hereafter described as a nonmagnetic ground layer) 5 which has a ground function. This nonmagnetic ground layer 5 is a layer containing at least one sort of elements chosen from Ta, Ti, Zr, W, Cr, Nb, Mo, Fe, and aluminum, and consists of compounds, such as these simple substance metals and alloys or an oxide, and a trioxide. When oxides, such as Ta<sub>2</sub>O<sub>5</sub>, are used for the nonmagnetic ground layer 5, the electron which was not able to be reflected in the improvement layer 4 in MR can be reflected by nonmagnetic ground layer 5 / improvement layer in MR 4 interface so that it may explain in full detail behind.

348] The 1st magnetic layer 1 is a magnetosensitive layer from which the magnetization direction changes with external magnetic fields. On the other hand, on the 2nd magnetic layer 2, the antiferromagnetism layer 6 which consists of IrMn, NiMn, PtMn, FeMn, RuRhMn, PdPtMn, MnO, etc. is formed. The bias magnetic field was given to the 2nd magnetic layer 2 from the antiferromagnetism layer 6, and the magnetization has fixed. That is, the 2nd magnetic layer is a magnetization fixing layer.

349] Although not illustrated in drawing 32, besides the method of touching an antiferromagnetism film directly as mentioned above as the fixing method of the 2nd magnetic layer, making carry out, and fixing the magnetization direction You may use the so-called synthetic anti ferro structure of carrying out the laminating of the 3rd magnetic layer through layers, such as Ru and Cr, on the 2nd magnetic layer, carrying out antiferromagnetism combination of the 2nd magnetic layer and 3rd magnetic layer in RKKY, and carrying out antiferromagnetism combination of the 3rd magnetic layer. By using synthetic anti ferro structure, a bias point also becomes stable and the stability under the elevated temperature of a pin property also increases. Specifically, CoFe/Ru/CoFe, Co/Ru/Co, CoFe/Cr/CoFe, Ru/Cr/Co, etc. are mentioned as composition from the 2nd magnetic layer to the 3rd magnetic layer. The antiferromagnetism film at this time is the same as that of a group of an above-mentioned antiferromagnetism film.

350] The alloy which makes a principal component Cu, Au, Ag and these alloys or the paramagnetic alloy containing these and a magnetic element, Pd and Pt, and these as a component of the 1st and 2nd magnetic layers 1 and the non-magnetic layer 3 arranged among two is illustrated.

351] The protective layer 7 is formed on the antiferromagnetism layer 6, and this protective layer 7 is constituted by the same metal or same alloy as the nonmagnetic ground layer 5. The spin bulb film 8 of this operation form is constituted by these each class. The electrode (not shown) of the couple which supplies sense current is connected to the spin bulb film 8, and a spin bulb GMR element is constituted by these. The spin bulb GMR element may have the bias magnetic field impression film which consists of a hard magnetic film which impresses a bias magnetic field to the magnetosensitive layer 1, or an antiferromagnetism film. In this case, as for a bias magnetic field, it is desirable to impress in the direction which carries out an abbreviation rectangular cross to the magnetization direction of the magnetization fixing layer 2. In addition, nine in drawing is a substrate.

352] The improvement layer 4 in MR which the improvement layer 4 in MR is the characteristic portion of this invention, and is shown in drawing 32 is constituted by the cascade screen of 1st metal membrane 4a and 2nd metal membrane 4b among each class which constitutes the spin bulb film 8 mentioned above. The metal membrane containing at least one sort of elements chosen from Cu, Au, Ag, Pt, Rh, aluminum, Ti, Zr, Hf, Pd, and Ir is applicable to the metal membranes 4a and 4b which function as a ground of the spin bulb film 8.

353] The element which mainly constitutes 1st metal membrane 4a which touches the 1st magnetic layer (magnetosensitive layer) 1 among the metal membranes of these plurality has a relation of the element which mainly constitutes the magnetosensitive layer 1, and not dissolving. It may be desirable to have a relation of the element with which the element which mainly constitutes it mainly constitutes the magnetosensitive layer 1 also about the 2nd metal membrane 4b, and not dissolving, and each element which mainly constitutes especially these [ 1st ] and the 2nd metal membrane 4a and 4b may have the relation of dissolution mutually. Furthermore, it is desirable to arrange 1st metal membrane 4a to which an electron wavelength becomes the side which touches the magnetosensitive layer 1 from a short metal, and to arrange 2nd metal membrane 4b with a long (1st metal membrane 1a) electron wavelength on the outside.

354] Here, the relation of not dissolving in this invention is stated. In this invention, the state of having a non-dissolving relation the element A, and two kinds of elements of the element B In the phase diagrams (for example, binary Alloy Phase Diagram, 2nd Edition, ASM International.1990, etc.) of two elements in the low-temperature region about a room temperature The combination of the element both the amount of atomic %s in which B can dissolve when A is used as a base material, and whose amount of atomic %s in which A can dissolve when it considers B base material are 10% or less shall be shown.

355] As an example, the time of a magnetic layer (for example, magnetosensitive layer 1) being Co or Co alloy and the case where a magnetic layer is nickel alloy are explained. Since it is desirable for ground films to be a fcc metal and a hcp metal in order to make a magnetic layer into fcc orientation, as a concrete composition element of the improvement layer in MR which touches a magnetic layer, aluminum, Ti, Cu, Zr, Ru, Rh, Pd, Ag, Hf, Ir, Pt, Au, etc. are mentioned. The element with which it is satisfied of the above-mentioned conditions of Co and un-dissolving, among these elements turns into three elements of Cu, Ag, and Au. Moreover, nickel and the element with which are satisfied of the above-mentioned conditions of un-dissolving turn into three elements of Ru, Ag, and Au. However, though Cu had the relation of dissolution when only the phase diagram was referred to when nickel alloy was used as magnetic layer, when it used as an improvement layer in MR as a result of this invention person's experiment, it became clear that it can say un-dissolving. That is, nickel alloy and Cu are judged un-dissolving based on the following experimental results.

356] Although the improvement layer in MR acts as a nonmagnetic quantity conductive layer in the 1st operation from mentioned above when \*\*\*\*\* and a free layer are thin, if atomic diffusion arises in the interface of a nonmagnetic quantity conductive layer and a free layer and it becomes a diffusive interface, the permeability of the electron which goes to a nonmagnetic quantity conductive layer from a free layer will be reduced. That is, in order that the magnetization direction of a pin layer and a free layer may receive inelastic scattering in a diffusive interface also the parallel state mutually, the mean free path of rise spin does not become long. That is, decline in MR rate of change will be caused. an ultra-thin free layer and the nonmagnetic quantity conductive layer of this phenomenon are dissolution -- by the way, it is generated, and it will become more remarkable if heat treatment of a process etc. is performed That is, MR rate of change falls with heat treatment. When the experiment which attached Cu to thin nickel alloy layer when the method of checking such a phenomenon was taken was conducted, decline in MR rate of change was not seen.

357] From the above result, nickel alloy and Cu are judged un-dissolving. Therefore, as nickel alloy and an element with which are satisfied of a non-dissolving relation, by this invention, Cu can be added to the combination of the element obtained from a phase diagram, and it can be defined as Ru, Ag, Au, and Cu. It is a mirror plane, without using the composition \*\*\*\*\* of the interface of a magnetic layer and the improvement layer in MR by heat treatment etc. by arranging the element of such not dissolving, in contact with a magnetic layer.

358] Here, although premised on carrying out fcc orientation of the magnetic layer, you may use these improvement layers in MR to the magnetic layer which, of course, has non-orientation and microcrystal structure. Specifically, the amorphous magnetic layer by which Ti, Zr, Nb, Hf, Mo, Ta, etc. were added, or a magnetic layer with microcrystal structure is mentioned to CoFeB, CoZrNb, and Cr as a magnetic layer.

359] Furthermore, in order to make control and the film fine structure of d-spacing into more exact structure to a part of improvement layer in MR constituted with the above-mentioned element, another element in making it a cascade screen with another metal membrane and the alloyed layer are improvement layers in MR by this invention. As an element which constitutes this film by which a laminating is carried out, a fcc metal and a hcp metal are desirable and aluminum, Ti, Cu, Zr, Ru, Rh, Pd, Ag, Hf, Ir, Pt, Au, etc. are mentioned.

360] When applying a cascade screen to the improvement layer in MR, the metal which has the metal membrane of the side which is in contact with the magnetic layer, and the relation of dissolution as a desirable example of the metal membrane of the side which is not in contact with a magnetic layer is mentioned. The combination of the element with which it is a low-temperature region about a room temperature, and both the amount of atomic %s in which B can dissolve when A is used as a base material, and the amount of atomic %s in which A can dissolve when it considers as B base material exceed 10% like the case of not dissolving [ which was described above as the state of having the relation of dissolution of the element A, and two kinds of elements of the element B here ] shall be shown.

361] The desirable example at the time of applying a cascade screen to the improvement layer in MR is shown. When a magnetic layer 1 consists of Cu(s) which fill the conditions of it and un-dissolving with Co or Co alloy, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from aluminum, Au, Pt, Rh, Pd, and Ir which fulfill the conditions of the above-mentioned dissolution. [ a / metal membrane ] When metal membrane 4a is constituted from Ag, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from Pt, Pd, and Au. When metal membrane 4a is constituted from

1, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from Pt, Pd, Ag, and aluminum. When a magnetic layer 1 consists of Ru which fills the conditions of it and non-dissolving with nickel alloy, as for metal membrane 4b, it is desirable to constitute from a metal membrane containing at least one sort chosen from Rh, Ir, and Pt which fulfill the conditions of the above-mentioned dissolution. [a / metal membrane 4] When using Ag and Au, it is as having described above.

[362] It is desirable for two elements which constitute the improvement layer 4 in MR among combination which was mentioned above to dissolve mutually 10% or more, for example, Au-Cu, Ag-Pt, Au-Pd, Pt-Cu, Au-Ag, etc. are mentioned. In addition, it is also possible for the combination of metal membrane 4a and metal membrane 4b not to give to fill the relation of the dissolution described above not necessarily, and to apply the combination of Cu-Ru and Cu-Ag etc. Not only the two-layer cascade screen of 1st metal membrane 4a and 2nd metal membrane 4b but the improvement layer 4 in MR which consists of a cascade screen can be constituted from a cascade screen of three or more layers.

[363] The improvement layer 4 in MR can also constitute the improvement layer 4 in MR from alloy-layer 4c of the element which mainly constitutes the magnetosensitive layer 1, and the element which has a non-dissolving relation, as shown not only in the cascade screen of 1st metal membrane 4a and 2nd metal membrane 4b but in drawing 33. The same view as the above-mentioned cascade screen is applicable to alloy-layer 4c in this case. That is, when a magnetic layer 1 consists of Co or a Co alloy, alloy-layer 4c contains at least one sort chosen from three elements of Cu, Ag, and Au as a main composition element. Moreover, when a magnetic layer 1 consists of a nickel alloy, alloy-layer 4c contains at least one sort chosen from four elements of Ru, Ag, Au, and Cu as a main composition element.

[364] Alloy-layer 4c contains at least one sort of elements in addition to the above-mentioned main composition element. The main composition element and the element of dissolution are used for elements other than this main composition element so that it may not become 2 phase separation films. For example, when Cu is used for the main composition element of alloy-layer 4c, the alloy of noble-metals systems, such as Cu-Au, Cu-Pt, Cu-Rh, Cu-Pd, and Cu-Ir, is used. When Ag is used for the main composition element of alloy-layer 4c, the alloy of noble-metals systems, such as Ag-Pt, Ag-Pd, and Ag-Au, is used. When Au is used for the main composition element of alloy-layer 4c, the alloy of noble-metals systems, such as Au-Pt, Au-Pd, Au-Ag, and Au-aluminum, is used.

[365] Among alloys which were mentioned above, as for alloy-layer 4c as an improvement layer 4 in MR, it is desirable for two elements to dissolve mutually 10% or more, for example, Au-Cu, Ag-Pt, Au-Pd, Au-Ag, etc. are mentioned. Thus, it is also possible to constitute the improvement layer 4 in MR from a cascade screen of metal membrane 4a and alloy-layer 4c, as various forms can be applied to the improvement layer 4 in MR, for example, it is shown in drawing 34.

[366] When using Co system magnetic material for the magnetosensitive layer 1, as for the improvement layer 4 in MR as a ground of the magnetosensitive layer 1, it is desirable to use the metallic material which has the same fcc crystal structure as Co system magnetic material, and the metallic material of the hcp structure to which it is easy to carry out fcc orientation of the film on it. Cu, Au, Ag, Pt, Rh, Pd, aluminum, Ti, Zr, Hf(s), Ir(s), etc. which were mentioned above also from such a point, and those alloys are suitable as a component of the improvement layer 4 in MR. Furthermore, by using the improvement layer 4 in MR which consists of the cascade screen or alloy layer of such metal, the magnetostriction of the magnetosensitive layer 1 which consists of Co system magnetic materials, such as CoFe alloy, can be reduced so that it may explain in full detail behind.

[367] In order to give the function as a ground layer, as for the thickness of the improvement layer 4 in MR, it is desirable to be referred to as 2nm or more. However, if it is made not much thick, in order that MR rate of change may decrease by increase of shunt diverging, it is desirable still more desirable to be referred to as 10nm or less, and the thickness of the improvement layer 4 in MR is 5nm or less.

[368] The work which raises the thermal resistance of the spin bulb film 8 as for the improvement layer 4 in MR which was mentioned above, It works. when the work as a specular reflection film (interface reflective film) of the spin bulb film 8 and a free layer are thin, MR rate of change is maintained to a high value -- It works, and has the work which reduces the magnetostriction of the magnetosensitive layer 1 which consists of a Co system magnetic material and which controls the crystal fine structure of the spin bulb film 8, and the MR property of the spin bulb film 8 is raised based on these. Below, work of the improvement layer 4 in MR is explained in full detail.

[369] First, thermal-process degradation of a spin bulb film is described. The mirror plane of the side which is not in contact with the nonmagnetic interlayer 3 of magnetic layers 1 and 2 as a cause of degradation of MR property by process annealing The situation is shown in drawing 35. In addition, it sets to drawing 35 and is IFS. The interface and FM by which spin dependence dispersion is carried out The interface by which not spin dependence dispersion but mirror-plane distraction is carried out is shown. Drawing 35 (a) and (b) show the ideal state (it corresponds at the time of as-depo), and drawing 35 (c) shows the state after process annealing typically.

[370] In the three-layer laminated structure of magnetosensitive layer 1 / nonmagnetic interlayer 2 / magnetization fixing layer 3 which serves as a basic unit of the spin bulb GMR as shown in drawing 35 (a) and (b) As shown in drawing 35 (c) (even if the interface is an interface with a metal membrane), what the mirror-plane scattering effect in the both sides had produced at the time of as-depo Interface diffusion arises by system which dissolves mutually easily / process annealing, and it becomes a dispersion-interface, and is a mirror plane.

[371] The mirror plane in a metal membrane interface For example, in an as-depo state with comparatively little mixing, it is a mirror plane also at a NiFe/CoFe interface.

[372] With the spin bulb film which used concretely the magnetosensitive layer which consists of a NiFe/CoFe cascade screen, it is the mirror plane of a NiFe/CoFe interface. It is also considered that change of MR rate of change / change of the specular reflection factor in the NiFe/CoFe interface by annealing took place as this cause.

[373]

---

nce it became timeout time, translation result display processing is stopped.

## NOTICES \*

Japan Patent Office is not responsible for any damages caused by the use of this translation.

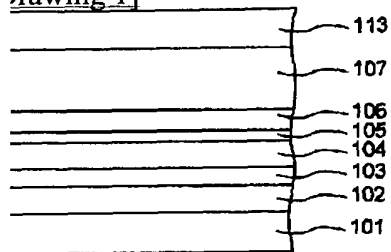
This document has been translated by computer. So the translation may not reflect the original precisely.

\*\*\*\* shows the word which can not be translated.

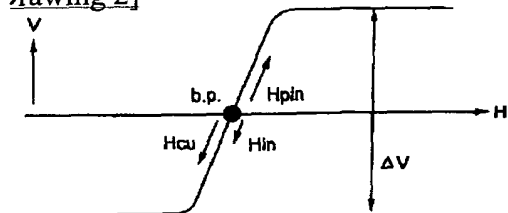
In the drawings, any words are not translated.

## DRAWINGS

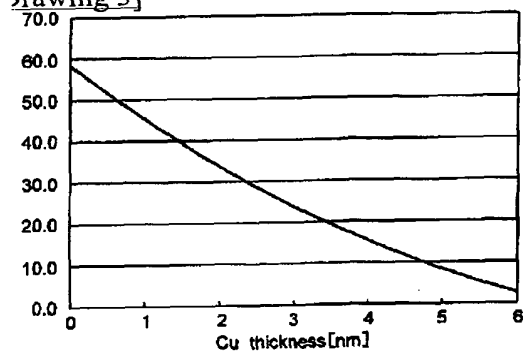
Drawing 1]



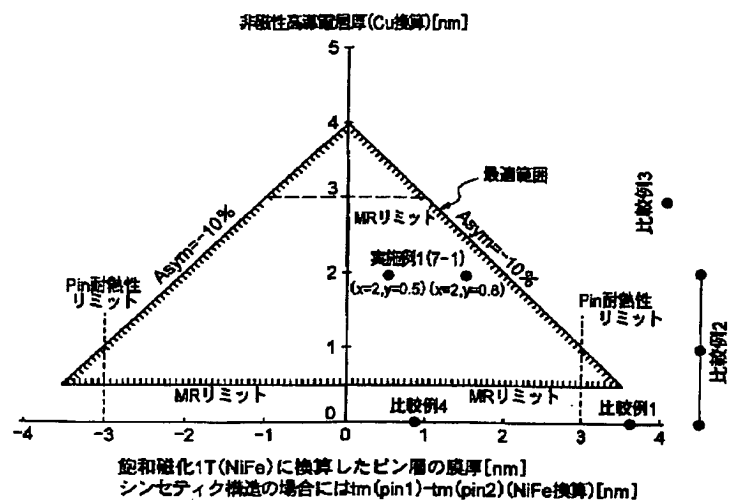
Drawing 2]



Drawing 3]

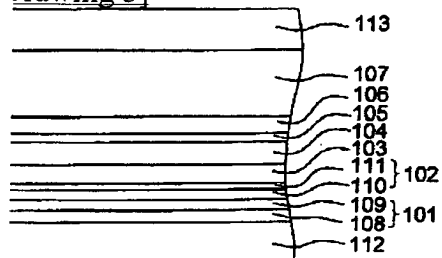


Drawing 4]



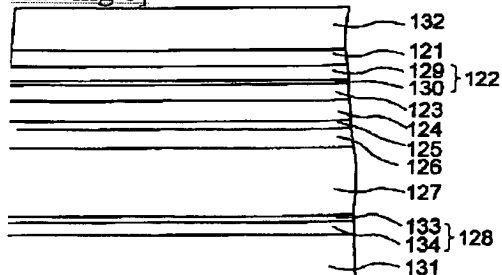
本発明による非磁性高導層の膜厚とピン層膜厚の範囲

Drawing 5]



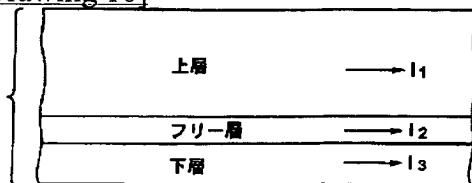
本発明(トップタイプでの実施例)

Drawing 6]



本発明(ボトムタイプでの実施例)

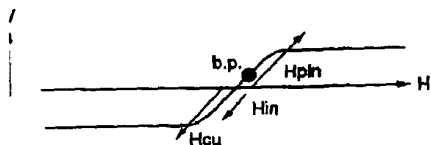
Drawing 10]



センス電流:  $I_S = I_1 + I_2 + I_3$  [mA]

スピンバルブ膜の電流分流通式図

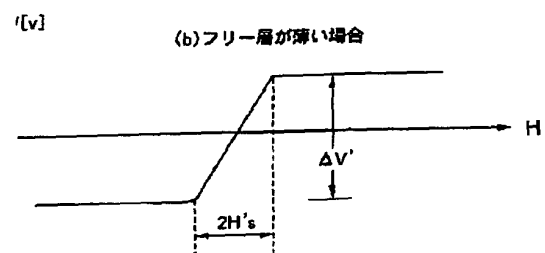
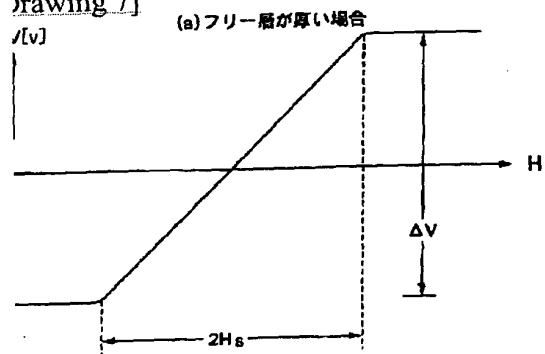
Drawing 11]



図例1 (Spin-Filterなしノーマルピン) のバイアスポイント

大きい  $H_{pin}$  を大きい  $H_{current}$  でジャストバイアス  
 にもってくるのは制御性が悪い (ハイト依存性が大きい)  
 Spin-Filter効果を用いていない為、出力が低下する

Figure 7]

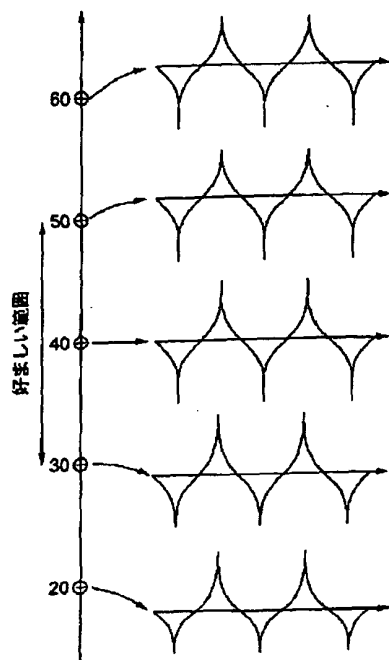


フリー層が薄くなったときの問題点

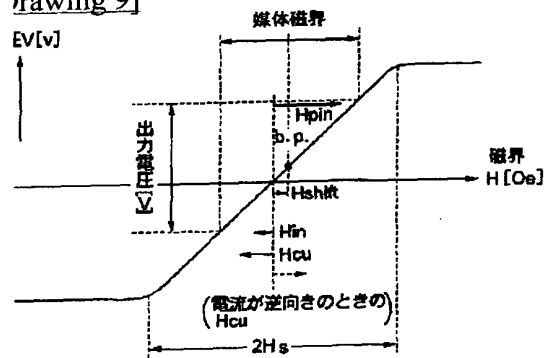
- $H's < H_s$  (傾きが急峻になる)  
 → バイアスポイントがとりづらくなる
- $\Delta V' < \Delta V$  (MR変化率が減少する)  
 → 出力がとれなくなる

Figure 8]

バイアスポイントとヘッド再生出力波形との関係



Drawing 9]

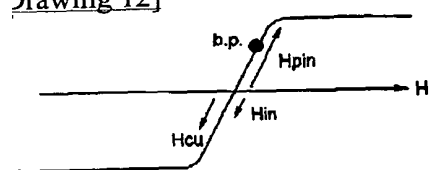


$$H_{shift} = -H_{in} + H_{pin} - H_{cu}$$

(または  $+H_{cu}$ )

トランスファークラップ上に示した  
バイアスポイント(b. d.)の概念図

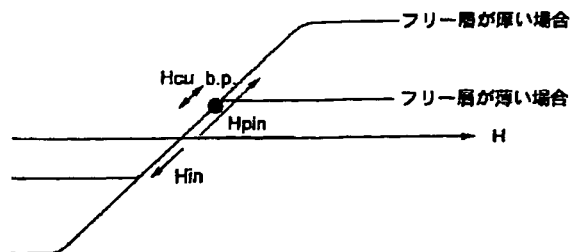
Drawing 12]



取例2 (Spin-FilterありXノーマルピン)のバイアスポイント

( $H_{pin}$ が大きく $H_{cu}$ は小さい為b.p.は  
50%よりもかなり大きくなってしまふ.)

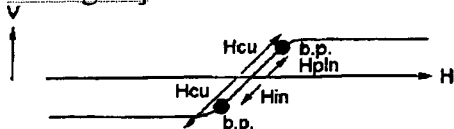
Drawing 13]



比較例3のバイアスポイント

- フリー層が厚い場合には、 $H_{cu}$ だけの低減でバイアスポイントが安定する。
- フリー層が薄くなると、 $H_{pin}$ の影響が大きく、b.p. がはずれる。さらにMRも劣化する。

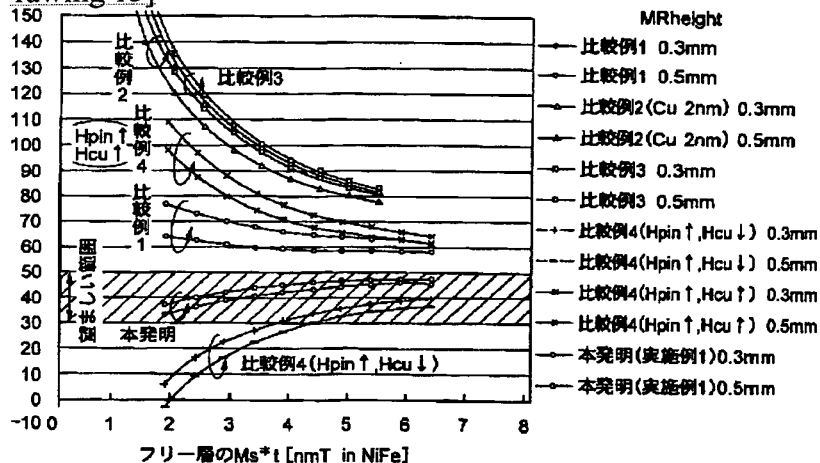
rawing 14]



例4 (Spin-FilterなしメシンセティックAF)のバイアスポイント

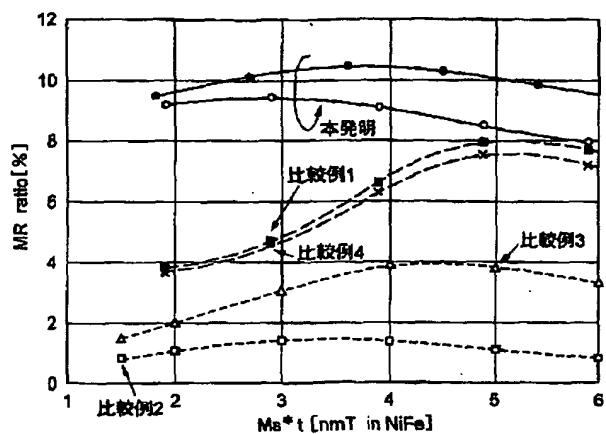
- $H_{in}, H_{pin}$  が小さく  $H_{in} + H_{pin}$  がほぼ50%に近いところで  $H_{current}$  が大きいと、電流をどちら向きに流してもジャストバイアスが得られなくなってしまう
- スピンフィルターがない為MRが減少する

rawing 15]

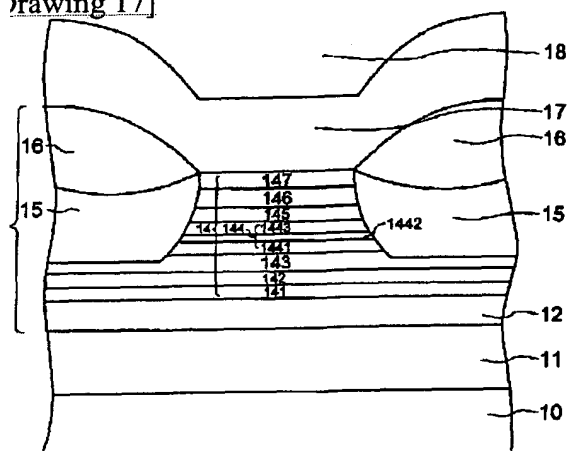


rawing 16]

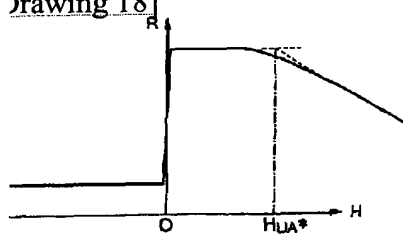
- 比較例1  
 比較例3  
 本発明(実施例1.下地Cu厚2nm固定)
- 比較例2 (下地Cu厚2nm固定)  
 比較例4  
 本発明(実施例2.下地Cu厚2nm固定)



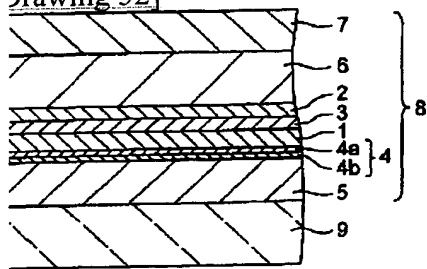
Drawing 17]



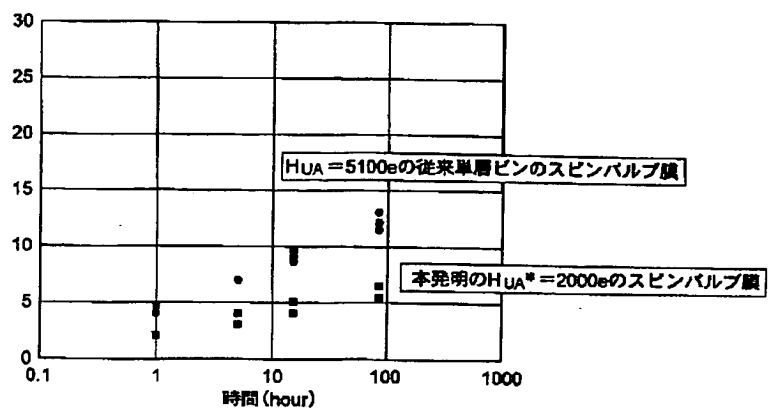
Drawing 18]



Drawing 32]

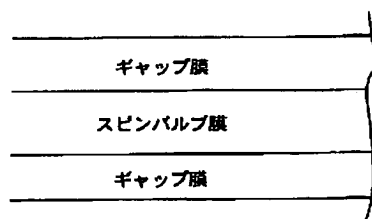
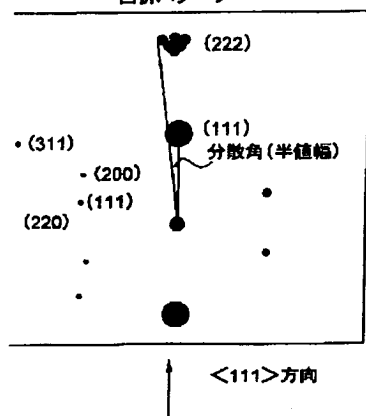


Drawing 19]



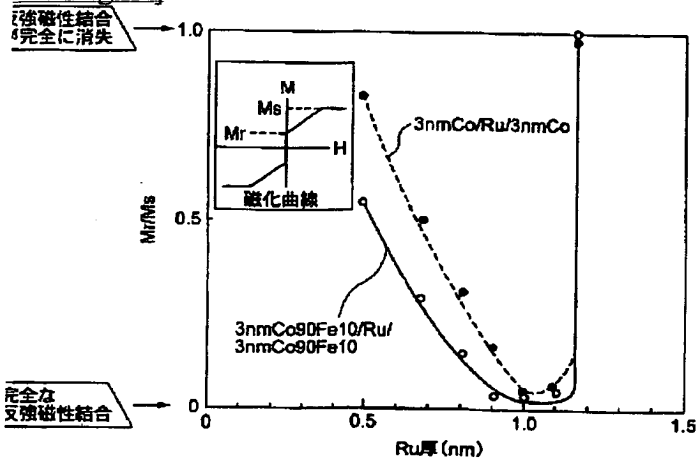
Drawing 20]

回折パターン

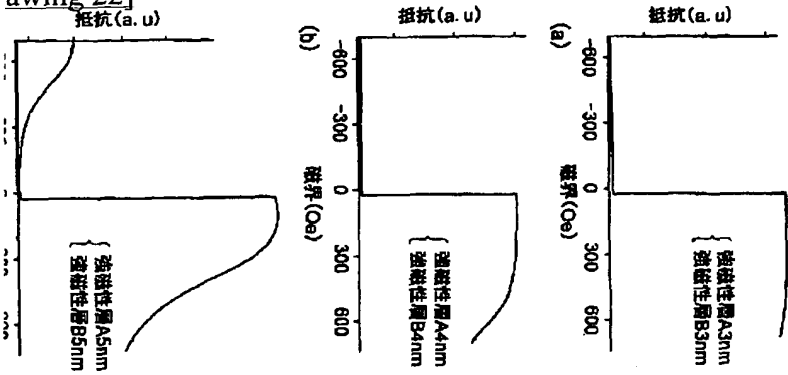


スピナバルブ素子部の断面

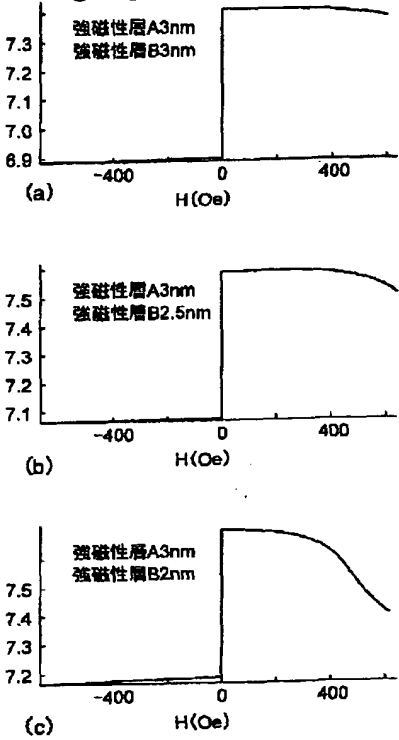
Drawing 21]

完全な  
反強磁性結合

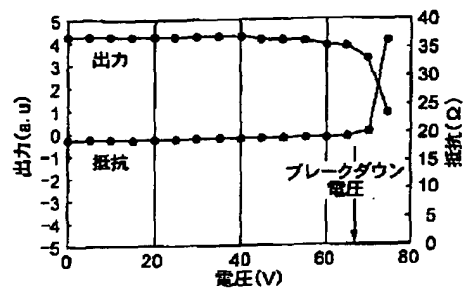
rawing 22]



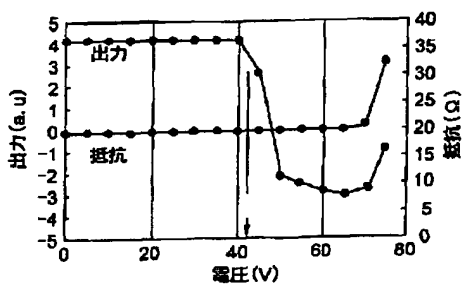
rawing 23]



rawing 24]



(a) +方向のESD電流



(b) -方向のESD電流

構成:

nTa/1.8nmNiFe/4nmCoFe/3nmCu

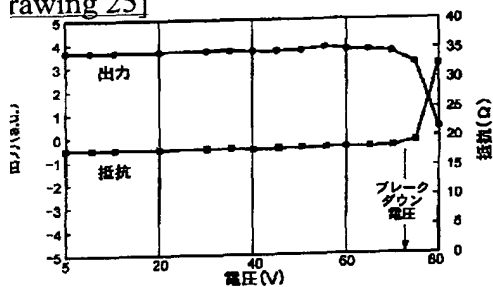
nCoFe/0.9nmRu/3nmCoFe/10nmIrMn/5nm

E:ヒューマンボディモデルによるESD電圧

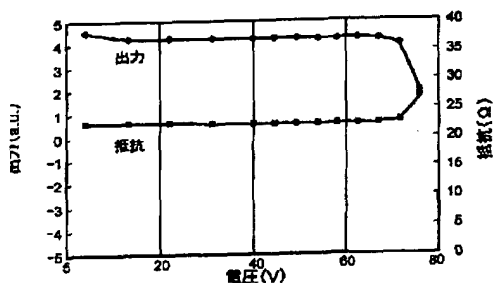
D電流:+方向はESD電流磁界が強磁性層Bの磁化と同方向に加わる方向}

B性層Aの強磁性層Bの磁気膜厚が薄い場合

rawing 25]



(c) +方向のESD電流



(d) -方向のESD電流

構成:

nmTa/1.8nmNiFe/4nmCoFe/3nmCu

nmCoFe/0.9nmRu/2.5nmCoFe/10nmIrMn/5nmTa

E:ヒューマンボディモデルによるESD電圧

D電流:+方向はESD電流磁界が強磁性層Bの磁化と同方向に加わる方向}

B性層Aの磁気膜厚>強磁性層Bの磁気膜厚の場合

rawing 26]

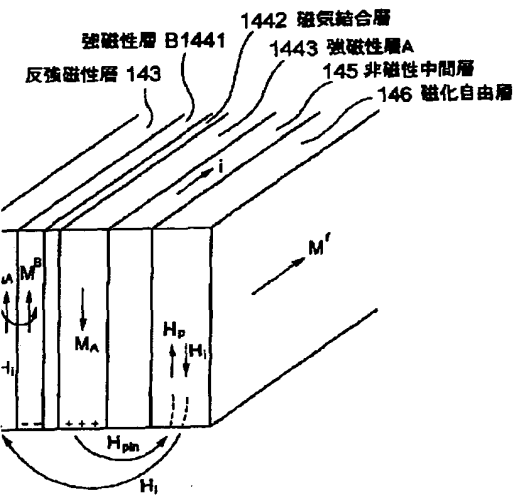


Figure 27]

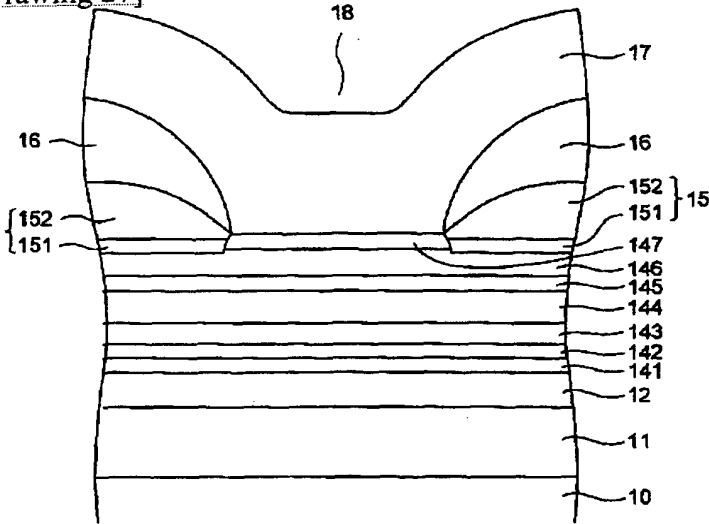


Figure 33]

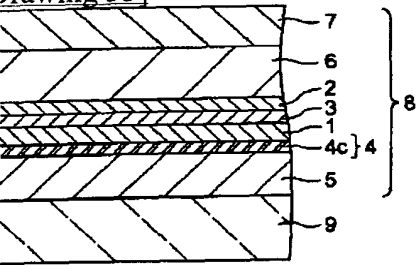


Figure 36]

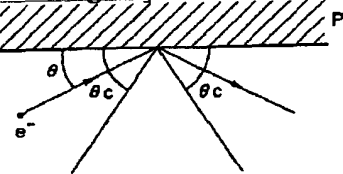
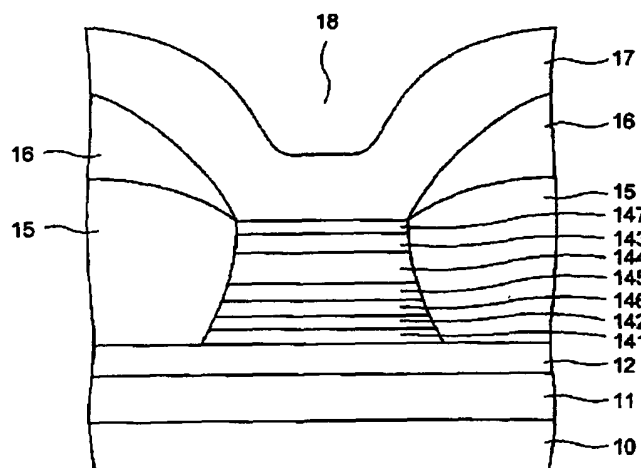
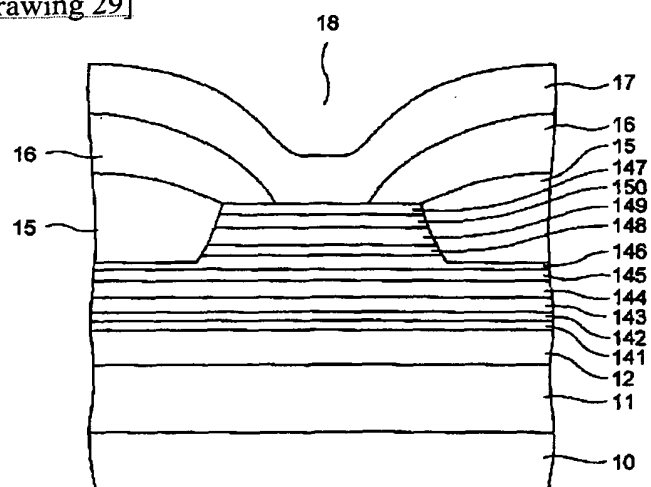


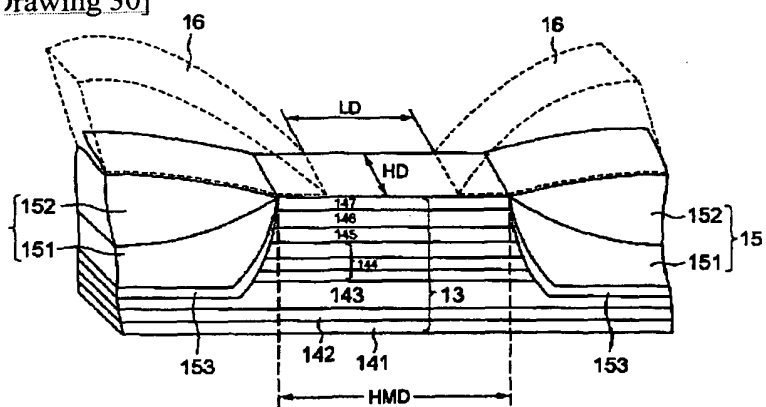
Figure 28]



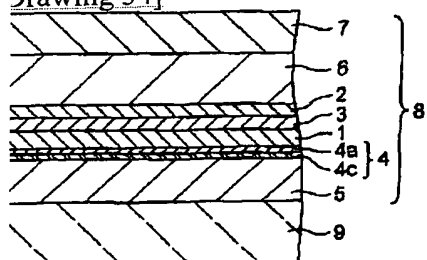
rawing 29]



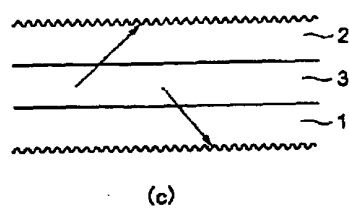
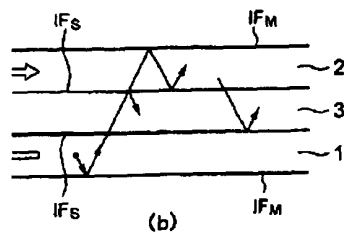
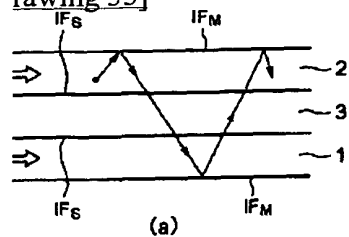
rawing 30]



rawing 34]

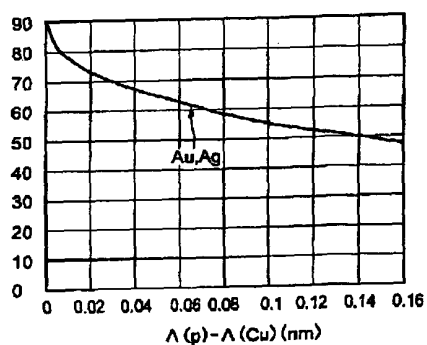


rawing 35]

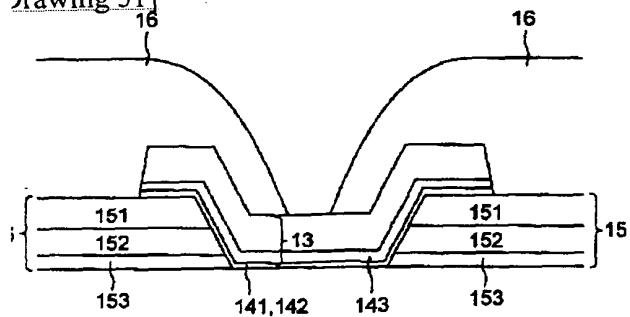


rawing 38]

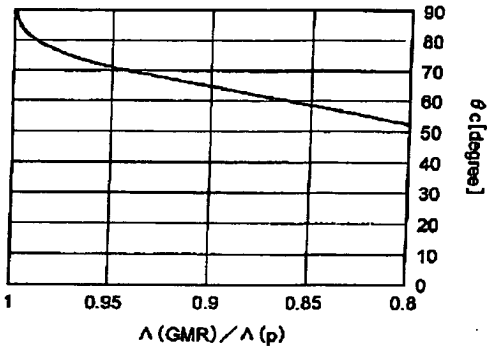
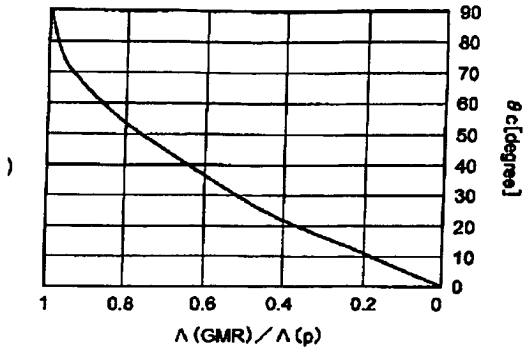
$\Lambda(\text{Cu}) = 0.4818 \text{ nm}$



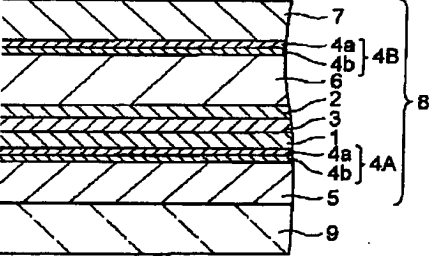
rawing 31]



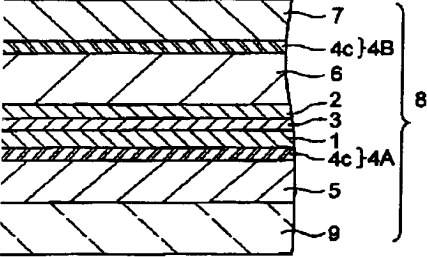
rawing 37]



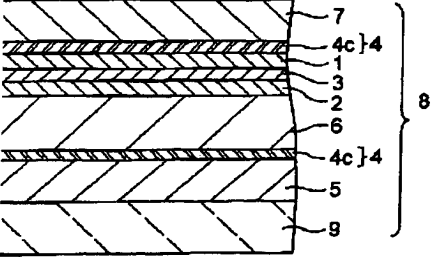
Drawing 39]



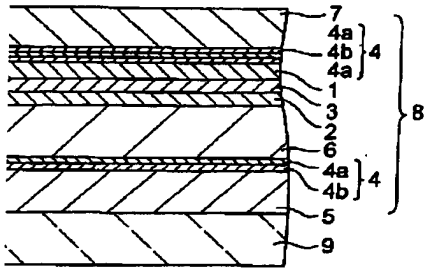
Drawing 40]



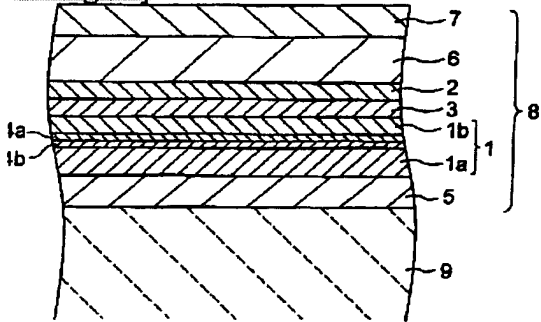
Drawing 41]



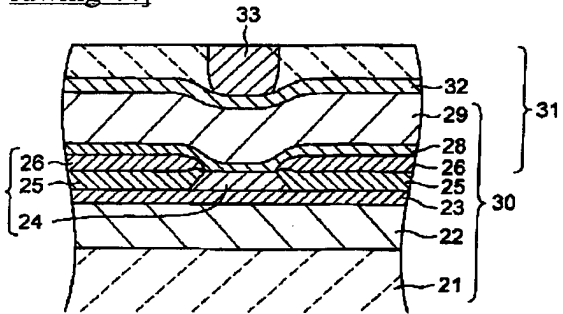
Drawing 42]



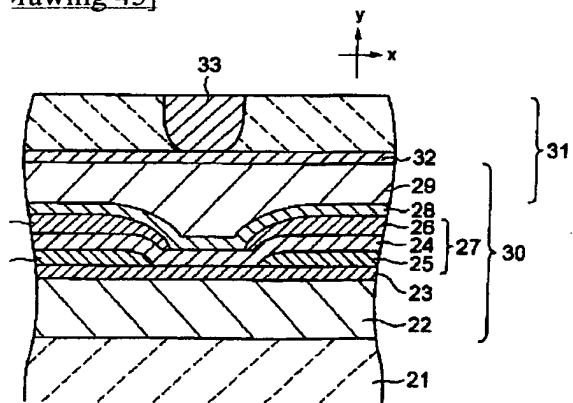
rawing 43]



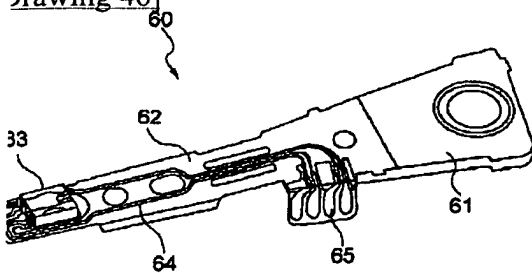
rawing 44]



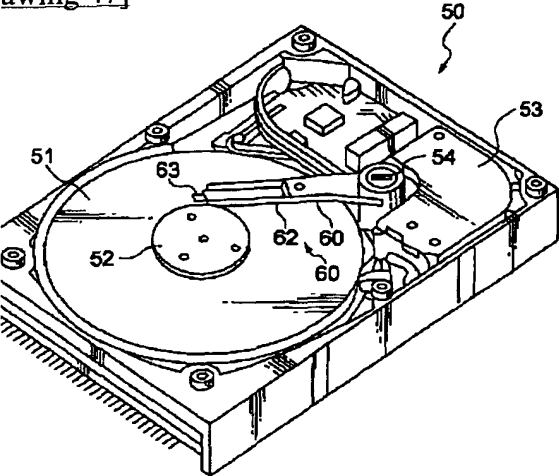
rawing 45]



rawing 46]



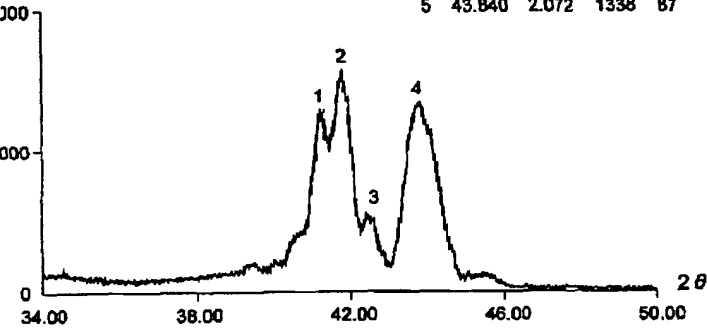
rawing 47]



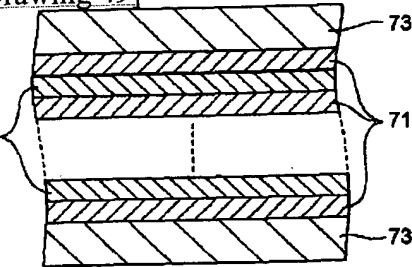
rawing 48]

ント 2θ-34.000 カウント=100

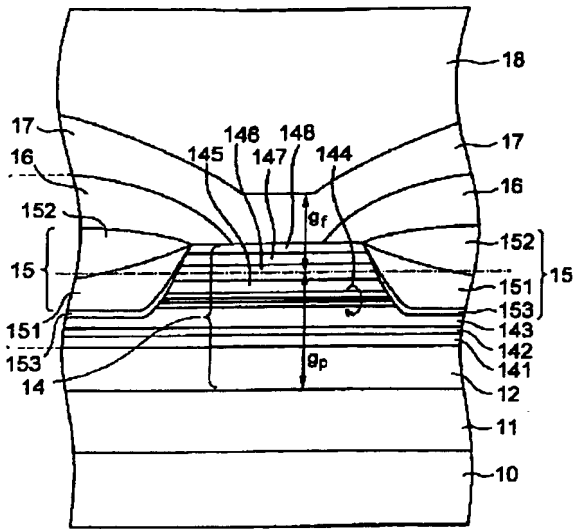
NRL	2θ	d	I	I/I <sub>0</sub>
1	41.020	2.198	1278	83
2	41.540	2.172	1535	100
3	42.320	2.134	505	33
4	43.600	2.074	1290	84
5	43.840	2.072	1338	87



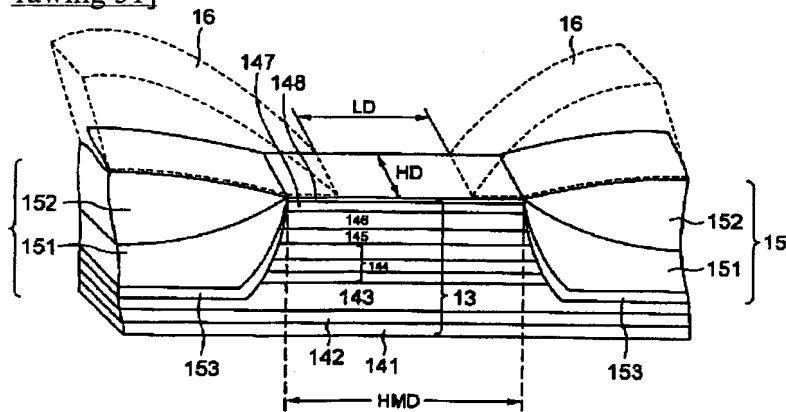
rawing 49]



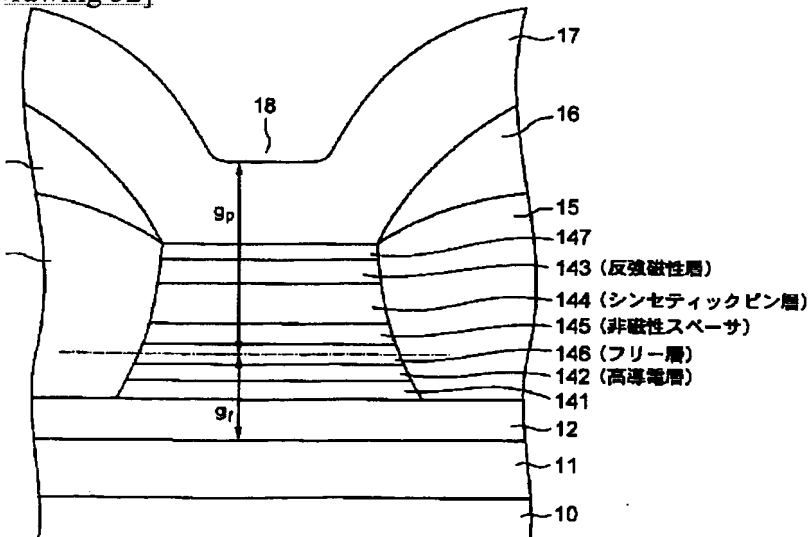
rawing 50]



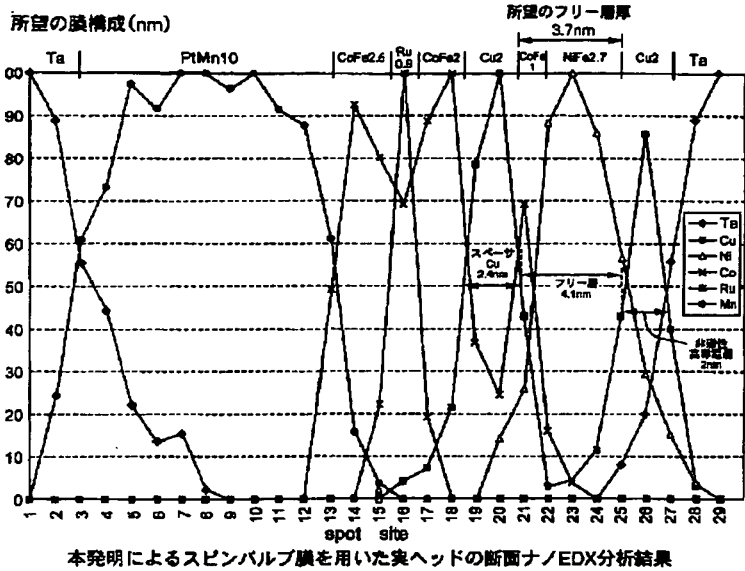
rawing 51]



rawing 52]



Drawing 53]



ranslation done.]

## NOTICES \*

Japan Patent Office is not responsible for any  
 damages caused by the use of this translation.

This document has been translated by computer. So the translation may not reflect the original precisely.

\*\*\*\*\* shows the word which can not be translated.

In the drawings, any words are not translated.

## CORRECTION or AMENDMENT

[Official Gazette Type] Printing of amendment by the convention of 2 of Article 17 of patent law.

[Section partition] The 4th partition of the 6th section.

[Date of issue] April 13, Heisei 13 (2001. 4.13)

[Publication No.] JP,2000-137906,A (P2000-137906A)

[Date of Publication] May 16, Heisei 12 (2000. 5.16)

[\*\*\* format] Open patent official report 12-1380.

[Filing Number] Japanese Patent Application No. 11-97072.

[The 7th edition of International Patent Classification]

1K 31/195 .  
 00 .

48 .  
 1P 17/00 .  
 /00 .  
 1K 31/165 .  
 /215 .  
 1B 5/39 .

I]  
 1K 31/195 .  
 00 C .

48 .  
 /00 617 .  
 :9 .  
 1B 5/39 .

[Procedure revision]

[Filing Date] April 3, Heisei 12 (2000. 4.3)

[Procedure amendment 1]

[Document to be Amended] Specification.

[Item(s) to be Amended] Claim.

[Method of Amendment] Change.

[Proposed Amendment]

[Claim(s)]

[Claim 1] A nonmagnetic spacer layer, and the 1st ferromagnetic layer and the 2nd ferromagnetic layer which were  
 separated by the aforementioned non-magnetic-material spacer layer,

\*\*\*\*\*,

the ferromagnetic layer of the above 1st has the magnetization direction which accomplishes the angle to which it has  
 received in the magnetization direction of the ferromagnetic layer of the above 2nd, when an impression magnetic field  
 zero.

the ferromagnetic layer of the above 2nd is a magnetoresistance-effect element containing the ferromagnetic film of

couple mutually combined in antiferromagnetism, and the joint film which combines these in antiferromagnetism, arating the ferromagnetic film of the aforementioned couple.

means to maintain one magnetization of the ferromagnetic films of the aforementioned couple in the ferromagnetic er of the above 2nd towards desired,

nonmagnetic quantity conductive layer which touches the 1st ferromagnetic layer in respect of the film surface ich the ferromagnetic layer of the above 1st and the aforementioned nonmagnetic spacer layer touch, and an osite side,

magnetoresistance-effect element characterized by \*\*\*\*(ing).

aim 2] The aforementioned nonmagnetic quantity conductive layer is a magnetoresistance-effect element according claim 1 characterized by containing the element whose value of the specific resistance in the room temperature of a k state is 10 or less microomegacm.

aim 3] The thickness of the aforementioned nonmagnetic quantity conductive layer converted into Cu of 10micro egacm of specific resistance  $t$  (HCL), When magnetic thickness which converted the thickness of the ferromagnetic n of the aforementioned couple in the ferromagnetic layer of the above 2nd by the saturation magnetization of 1T is to  $t_m$  (pin1) and  $t_m$  (pin2) ( $t_m$ (pin1) > it is referred to as  $t_m$  (pin2)), respectively The magnetoresistance-effect ment according to claim 1 or 2 characterized by satisfying  $0.5 \text{ nm} \leq t_m(\text{pin1}) - t_m(\text{pin2}) + t(\text{HCL}) \leq 4 \text{ nm}$  and  $t(\text{HCL}) \leq 0.5 \text{ nm}$ .

aim 4] The magnetoresistance-effect element according to claim 1 or 2 to which wave asymmetry  $(V1 - V2) / (1 + V2)$  expressed with the absolute value  $V1$  of the reproduction output in a right signal magnetic field and the solute value  $V2$  of the reproduction output in a negative signal magnetic field is characterized by setting up the ckness of the aforementioned nonmagnetic quantity conductive layer, and the thickness of the ferromagnetic layer of : above 2nd so that it may become 0.1 or less 0.1 or more minus plus.

aim 5] The thickness of the ferromagnetic layer of the above 1st is the magnetoresistance-effect element of any one blication of the claim 1-4 characterized by 0.5nm or more being 4.5nm or less.

aim 6] The ferromagnetic layer of the above 1st is the magnetoresistance-effect element of any one publication of : claim 1-5 characterized by the bird clapper from the cascade screen of the alloy layer containing a ferronickel iFe), and the layer containing cobalt (Co).

aim 7] The ferromagnetic layer of the above 1st is the magnetoresistance-effect element of any one publication of : claim 1-5 characterized by the bird clapper from the alloy layer containing cobalt iron (CoFe).

aim 8] The aforementioned nonmagnetic quantity conductive layer Copper (Cu), gold (Au), silver (Ag), a thenium (Ru), Iridium (Ir), a rhenium (Re), a rhodium (Rh), platinum (Pt), The magnetoresistance-effect element of y one publication of the claim 1-5 characterized by being the metal membrane which contains at least a kind of etallic element chosen from the group which consists of palladium (Pd), aluminum (aluminum), an osmium (Os), and skel (nickel).

aim 9] The aforementioned nonmagnetic quantity conductive layer is the magnetoresistance-effect element of any ie publication of the claim 1-5 characterized by being formed from the cascade screen which carried out the minating of the film more than two-layer at least.

aim 10] The magnetoresistance-effect element according to claim 9 characterized by the film which touches the romagnetic layer of the above 1st among the aforementioned cascade screens containing copper (Cu).

aim 11] The magnetoresistance-effect element according to claim 10 characterized by including at least a kind of ement chosen from the group which the film which does not touch the ferromagnetic layer of the above 1st among e aforementioned cascade screens becomes from a ruthenium (Ru), a rhenium (Re), a rhodium (Rh), palladium (Pd), atinum (Pt), iridium (Ir), and an osmium (Os).

aim 12] The magnetoresistance-effect element of any one publication of the claim 1-5 characterized by the element hich mainly constitutes the aforementioned nonmagnetic quantity conductive layer, and the element which mainly onstitutes the ferromagnetic layer of the above 1st having a relation [ \*\*\*\* / un-] mutually in the touching interface of e aforementioned nonmagnetic quantity conductive layer and the ferromagnetic layer of the above 1st.

aim 13] It has further an antiferromagnetism layer as a means to maintain one magnetization of the ferromagnetic lms of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired.

s a material of the aforementioned antiferromagnetic substance layer, it is  $X_z\text{Mn}1-z$  (X here). Iridium (Ir), a thenium (Ru), a rhodium (Rh), platinum (Pt), at least a kind of element chosen from the group which consists of alladium (Pd) and a rhenium (Re) -- carrying out -- the composition ratio  $z$  -- more than 5 atom % -- below 40 atom % it is -- the claims 1-5 characterized by using -- someday -- the magnetoresistance-effect element of one publication

aim 14] It has further an antiferromagnetism layer as a means to maintain one magnetization of the ferromagnetic lms of the aforementioned couple in the ferromagnetic layer of the above 2nd towards desired.

a magnetoresistance-effect element of any one publication of the claim 1-5 characterized by using  $XzMn_{1-z}$  (X considering as a kind of element chosen from the group which consists of platinum (Pt) and palladium (Pd) at least one, and the composition ratio z being below 65 atom % more than 40 atom %) as a material of the aforementioned ferromagnetism layer.

claim 15] The magnetoresistance-effect element of any one publication of the claim 1-5 characterized by having provided the aforementioned nonmagnetic quantity conductive layer in the ferromagnetic layer of the above 1st, and the side of an opposite side, and having further the layer which contains at least a kind of element chosen from the group which consists of a tantalum (Ta), titanium (Ti), a zirconium (Zr), a tungsten (W), a hafnium (Hf), and molybdenum (Mo).

claim 16] The magnetic head characterized by having the magnetoresistance-effect element of any one publication of the claim 1-15.

claim 17] Bottom magnetic-shielding layer,

the bottom reproduction magnetic-gap layer prepared on the aforementioned bottom magnetic-shielding layer,

the magnetoresistance-effect element of any one publication of the claim 1-15 prepared on the aforementioned bottom reproduction magnetic-gap layer,

the bottom reproduction magnetic-gap layer prepared on the aforementioned magnetoresistance-effect element.

the top magnetic-shielding layer prepared on the aforementioned top magnetic-gap layer,

the magnetic head characterized by \*\*\*\*\* (ing).

claim 18] The magnetic head according to claim 17 characterized by the irregularity of the front face of the aforementioned bottom reproduction magnetic-gap layer in a magnetic force sensor being smaller than the thickness of the aforementioned joint film.

claim 19] The aforementioned nonmagnetic spacer layer is provided from the center which saw the ferromagnetic layer of the above 1st in the direction of thickness. The aforementioned top magnetic-shielding layer and the aforementioned bottom magnetic-shielding layer either, without providing the aforementioned nonmagnetic spacer layer from the center which saw D1 and the ferromagnetic layer of the above 1st for the distance which results in the aforementioned top magnetic-shielding layer or the aforementioned bottom magnetic-shielding layer in the direction of thickness when the distance which reaches another side is set to D2  $D1 > D2$  The magnetic head according to claim 17 or 18 characterized by the distance D2.

claim 20] The bottom magnetic pole which was communalized with the aforementioned top magnetic-shielding layer, was prepared,

the record magnetic-gap layer prepared on the aforementioned bottom magnetic pole,

the top magnetic pole prepared on the aforementioned record magnetic-gap layer,

the magnetic head of any one publication of the claim 17-19 characterized by having the recording head which \*\*\*\*\* rather.

claim 21] The head slider which has the magnetic head according to claim 16 or 20,

the arm which has the suspension in which the aforementioned head slider was carried,

the magnetic-head assembly characterized by \*\*\*\*\* (ing).

claim 22] Magnetic-recording medium,

magnetic-head assembly according to claim 20,

the magnetic recording medium characterized by \*\*\*\*\* (ing).

Procedure amendment 2]

Document to be Amended] Specification.

Item(s) to be Amended] 0306.

Method of Amendment] Change.

Proposed Amendment]

0306] (Form 7 : the thermal resistance and the mirror plane of operation)

ext, "thermal resistance and a mirror plane

Procedure amendment 3]

Document to be Amended] Specification.

Item(s) to be Amended] 0416.

Method of Amendment] Change.

Proposed Amendment]

0416] In drawing 44 and drawing 45, the bottom reproduction magnetic gap 28 which consists of the same nonmagnetic insulating material as the bottom reproduction magnetic gap 23 is formed on the GMR reproduction element section 27. Furthermore, on the bottom reproduction magnetic gap 28, the top magnetic-shielding layer 29

ich consists of the same soft magnetic materials as the bottom magnetic-shielding layer 22 is formed. Shielded type MR head 30 as the reproducing head is constituted by each [ these ] component.

Procedure amendment 4]

Document to be Amended] Specification.

Item(s) to be Amended] 0417.

Method of Amendment] Change.

Proposed Amendment]

0417] The thin film magnetic head 31 is formed on shielded type GMR head 30 as a recording head. It is constituted by the bottom record magnetic pole gear tooth of the thin film magnetic head 31, the top magnetic-shielding layer 29, and the common magnetic layer. The top magnetic-shielding layer 29 of shielded type GMR head 30 serves as the bottom record magnetic pole of the thin film magnetic head 31. The bottom record magnetic pole 29 top which serves as a besides side magnetic-shielding layer -- AlOx etc. -- the record magnetic pole gap 32 and the bottom record magnetic pole 33 which consist of a nonmagnetic insulating material are formed in order. The record coil (not shown) which gives a record magnetic field to the bottom record magnetic pole 29 and the bottom record magnetic pole 33 is formed in the back side from the medium opposed face.

Procedure amendment 5]

Document to be Amended] Specification.

Item(s) to be Amended] 0418.

Method of Amendment] Change.

Proposed Amendment]

0418] The rec/play separate-type magnetic head is constituted by the thin film magnetic head 31 as shielded type MR head 30 and recording head as the reproducing head mentioned above. Such the rec/play separate-type magnetic head is carried in the magnetic-head assembly which it is included in a head slider, for example, is shown in drawing 45. The magnetic-head assembly 60 shown in drawing 46 has the actuator arm 61 which has the bobbin section holding drive coil etc., and the suspension 62 is connected to the end of the actuator arm 61.

Procedure amendment 6]

Document to be Amended] Specification.

Item(s) to be Amended] 0441.

Method of Amendment] Change.

Proposed Amendment]

0441] The above-mentioned nonmagnetic ground layer is not only metal membranes, such as Ta, but TaOx. An oxide film [ like ] can also be used, and it replaces with Ta, and is TaOx. When a ground was used, the good effect was required similarly. In this case, it is Ta Ox with a large potential difference about the electron which was not able to be reflected in the improvement layer in MR. It can be made to be able to reflect by the ground / improvement layer interface in MR, and MR rate of change can be raised further. However, TaOx If direct CoFe is formed on a ground layer, fcc (111) orientation will not be carried out, and a fcc-d (111) spacing desirable in magnetostriction is not obtained. On the other hand, a TaOx/Au/Cu ground is excellent in practicality. TaOx It can replace with and oxides, such as Ti, Zr, Cr, W, Hf, and Nb, can also be used. Moreover, a nitride like TiN and TaN can also be used.

Example 2)

In this example 2, the spin bulb film of Ta(5nm)/Au(1nm)/Cu(1nm)/CoFe(4nm)/Cu(2.5nm)/CoFe(2.5nm)/IrMn(1nm)/Au(0.5nm)/Cu(0.5nm)/Ta (5nm) structure was produced like the example 1.

Procedure amendment 7]

Document to be Amended] Specification.

Item(s) to be Amended] 0465.

Method of Amendment] Change.

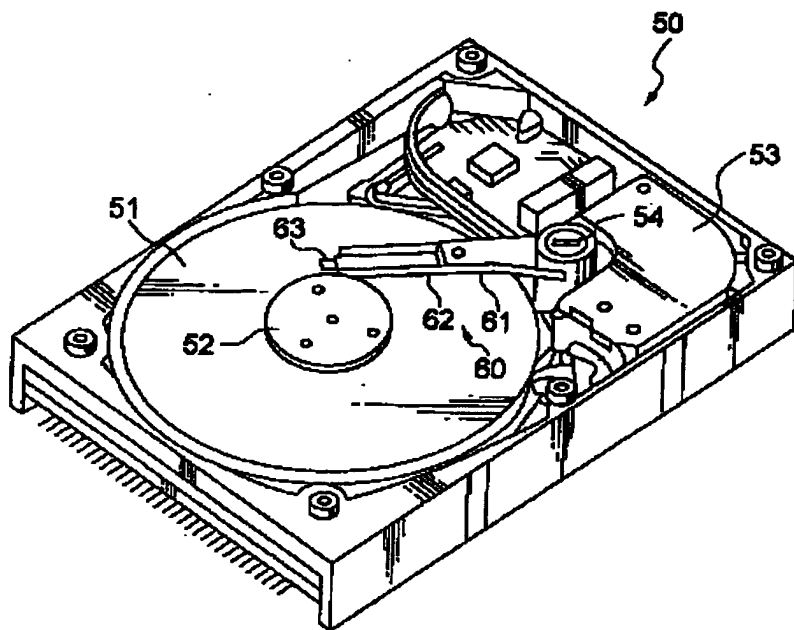
Proposed Amendment]

0465] Since the grain boundary constituting the electronic cause of dispersion stops almost existing, an electronic mean free path also becomes long, and the structure near such a single crystal is also raising the absolute value of MR rate of change, and it not only excels in the thermal resistance of MR rate of change and magnetic properties, but it is a desirable membrane structure. The technology of acquiring the structure near such a single crystal on an amorphous substrate like thermal oxidation silicon and an amorphous alumina is also one of the features of this invention.

\*\*\*\*\* on the amorphous AlOx film on the AlTiC substrate usually used with the actual head, and other oxide system amorphous films, a nitride system amorphous film, and diamond-like carbon although the thermal oxidation silicon substrate was used here.

Procedure amendment 8]

Document to be Amended] DRAWINGS  
 (m(s) to be Amended] Drawing 47.  
 Method of Amendment] Change.  
 Proposed Amendment]  
 Drawing 47]




---

translation done.]